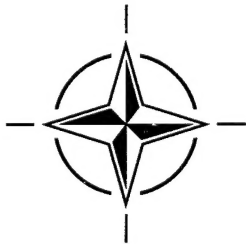# AGARD

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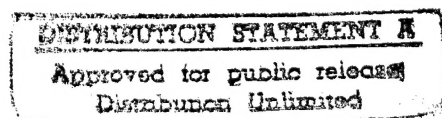
AGARD ADVISORY REPORT 340

Structures and Materials Panel Working Group 27 on

Evaluation of Loads from Operational Flight Maneuvers
Final Working Group Report
(l'Evaluation des charges résultant des manœuvres en vol)

This report was prepared at the request of the Structures and Materials Panel of AGARD.

NORTH ATLANTIC TREATY ORGANIZATION

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Published April 1996

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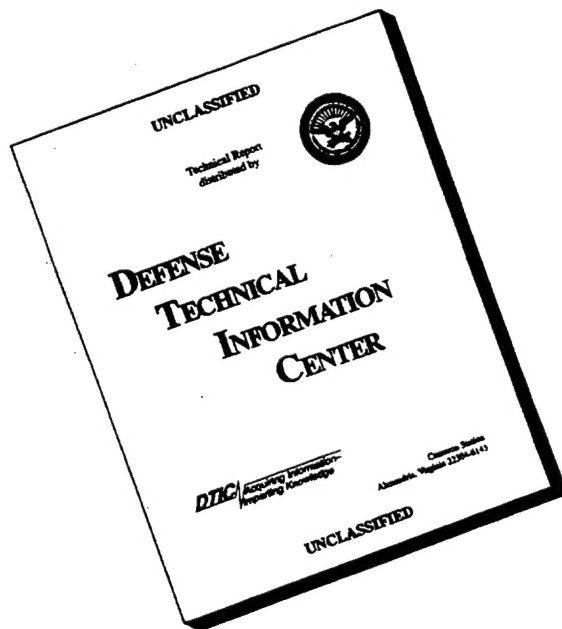This report was prepared at the request of the Structures and Materials Panel of AGARD.

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— Recommending effective ways for the member nations to use their research and development capabilities for the common benefit of the NATO community;

— Providing scientific and technical advice and assistance to the Military Committee in the field of aerospace research and development (with particular regard to its military application);

— Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;

— Improving the co-operation among member nations in aerospace research and development;

— Exchange of scientific and technical information;

— Providing assistance to member nations for the purpose of increasing their scientific and technical potential;

— Rendering scientific and technical assistance, as requested, to other NATO bodies and to member nations in connection with research and development problems in the aerospace field.

The highest authority within AGARD is the National Delegates Board consisting of officially appointed senior representatives from each member nation. The mission of AGARD is carried out through the Panels which are composed of experts appointed by the National Delegates, the Consultant and Exchange Programme and the Aerospace Applications Studies Programme. The results of AGARD work are reported to the member nations and the NATO Authorities through the AGARD series of publications of which this is one.

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Evaluation of Loads from Operational Flight Maneuvers
(AGARD AR-340)

Executive Summary

This AGARD Advisory Report describes an evaluation of a method to derive loads from operational flight maneuvers. The basic assumption of this method is that all operational maneuvers performed in service can be verified as a set of Standard Maneuvers (normalized parameter time histories for each independent maneuver type).

The normalization procedure has been developed and applied to the data base for 3 GAF-aircraft in operation and one aircraft in development. The verification of Standard Maneuvers is based on recordings of relevant maneuver parameters in service and for new tactics/missions on special flights or simulations.

For the verification process, data from the USAF and CF maneuver types have been identified and normalized. The comparison of the normalized maneuvers for several aircraft types leads to similar parameter time histories for the same maneuver type.

The study has demonstrated for two Standard Maneuver types that load relevant parameters can be derived with sufficient accuracy for load calculations. Standard maneuvers derived from F-16 data were reconstituted using F-18 control parameters. An F-18 loads calculation process has been verified against flight test data. A comparison of the input parameters and the resulting loads was carried out which showed reasonable correlation.

The initial evaluation of the concept done by WG27 has demonstrated the feasibility of determining loads from operational flight maneuvers. Further work is necessary to expand the scope of the WG27 investigation and to confirm the WG27 conclusion.

L'évaluation des charges à partir des manœuvres opérationnelles
(AGARD AR-340)

Synthèse

Ce rapport consultatif AGARD présente l'évaluation d'une méthode pour la détermination des charges à partir de manœuvres opérationnelles. L'hypothèse de base qui sous-tend cette méthode est que l'ensemble des manœuvres opérationnelles exécutées en vol peuvent être vérifiées en tant qu'un ensemble de manœuvres standard (il s'agit d'histogrammes paramètres/temps normalisés par type de manœuvre).

La procédure de normalisation a été élaborée et appliquée à la base de données établie pour 3 aéronefs en service dans l'armée de l'air allemande et pour 1 aéronef en cours de développement. La vérification des manœuvres standard est basée sur l'enregistrement en vol des paramètres de manœuvre pertinents. Dans le cas de missions et de tactiques nouvelles, soit la simulation, soit des vols spécifiques sont utilisés.

En ce qui concerne le processus de vérification, des données relatives aux manœuvres pratiquées par les forces USAF et Canadiennes ont été identifiées et normalisées. La comparaison des manœuvres normalisées pour plusieurs types d'aéronefs donne des histogrammes paramètres/temps similaires pour un même type de manœuvre.

L'étude a démontré, dans le cas de deux manœuvres standard, que les paramètres relatifs aux charges peuvent être dérivés avec une précision suffisante pour permettre le calcul des charges. Des manœuvres standard dérivés de données F-16 ont été reconstituées en utilisant des paramètres de contrôle du F-18. Un processus de calcul de charges pour un F-18 a été vérifié par rapport à des données d'essais en vol. La comparaison des paramètres d'entrée avec les charges obtenues conséquemment a permis de constater une corrélation acceptable.

L'évaluation initiale du concept, effectuée par le WG 27, a démontré la faisabilité de la détermination des charges à partir des manœuvres opérationnelles. Cependant, des travaux supplémentaires sont nécessaires, afin d'élargir le domaine d'investigation du WG 27 et de confirmer ses conclusions.

Contents

Preface

Existing design load regulations and specifications based on conventional aircraft configurations and control systems may not be adequate to ensure structural integrity of future military aircraft configurations using novel control methods, structural concepts and combat tactics. Equally, in some cases, the existing regulations and specifications may lead to over-conservatism.

For this reason, the AGARD Structures and Materials Panel has been involved in this field since the mid-1980's looking for alternative approaches to establish design loads for actively controlled aircraft. One promising approach, formulated by H. Struck (GE), is to derive design loads from a careful analysis of operational maneuvers by current fighters to extract critical parameters and their range of values. The basis of the approach was a maneuver model developed under the direction of H. Struck to evaluate NATO maneuvers performed at the test center of the German Air Force on three types of aircraft. This work was first sponsored by the German Ministry of Defence and later by DASA (GE).

To investigate this approach further, Working Group 27 "Evaluation of Loads from Operational Flight Maneuver" was formed. AGARD involvement was particularly relevant since it allowed the expansion of the types of aircraft and control systems considered in the study. The Working Group formulated a set of activities that addressed the fundamental premises of a method to generate operational loads from flight parameters by determination of Standard Maneuvers independent of the aircraft type and the control system. These operational loads can be statistically evaluated for use in static design and for fatigue and fracture assessments. Necessarily, WG.27 activities were influenced by its 2-year mandate and a practical set of activities were identified that would address the fundamental issues.

This report describes the results of the WG.27 investigation.

The interest and devoted work of the members of the Working Group are gratefully acknowledged. In particular, H. Struck (GE) provided the technical guidance for the work and with the assistance of his colleague J. Molkenthin (GE), performed most of the analytical studies. C. Perron (CA) was a consistent contributor to the work, particularly in the evaluation process. The usage data was made available from three AGARD nations (GE, US, CA) and special acknowledgement is given to C. Petrin (US) and Major M. Zgela (CA) for providing extensive data from their respective fleets.

The Working Group would also like to acknowledge the constructive comments received on the final report from J. Ellis (US), J.B. deJonge (NL), J. Coyle (US), C. Perron (CA) and C. Petrin (US).

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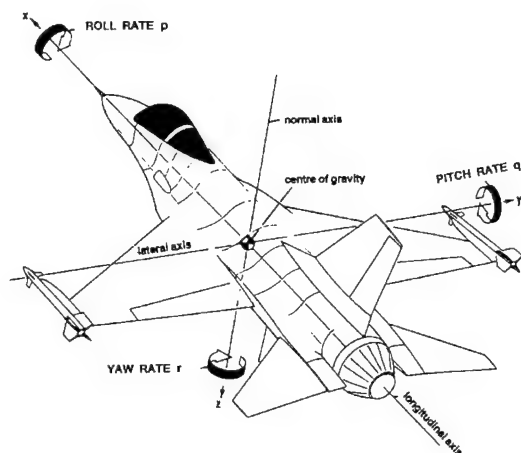92200 Neuilly-sur-Seine
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1. NOMENCLATURE
## 1.1 Sign Convention

Aircraft – Axes and Designations

ROLL RATE p
normal axis
centre of gravity
PITCH RATE q
lateral axis
YAW RATE r
longitudinal axis

Symbols

n_y	=	Lateral Load Factor	
n_z	=	Normal Load Factor	
p	=	Roll Rate	(deg/sec)
q	=	Pitch Rate	(deg/sec)
r	=	Yaw Rate	(deg/sec)

Body – Axes System

x	=	Longitudinal Axes
y	=	Lateral Axes
z	=	Normal Axes

Relation Between Aircraft – Normal Earth Axes System and Body Axes System

HORIZONTAL-LEVEL
Z, X - LEVEL
CENTRE OF GRAVITY
Y, Z - LEVEL
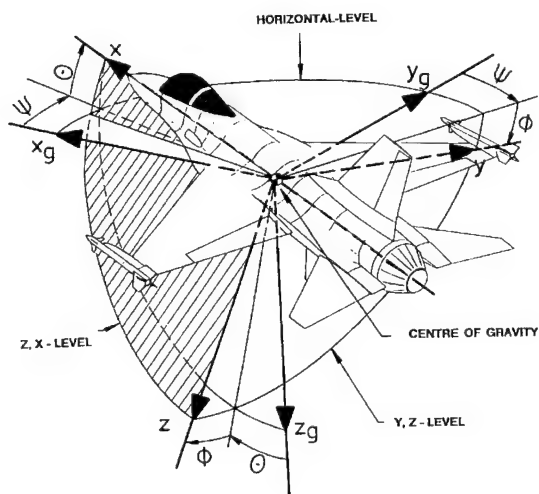
Normal Earth, Axes System

x_g
y_g
z_g

Body – Axes System

x	=	Longitudinal Axes
y	=	Lateral Axes
z	=	Normal Axes

Relations

Φ	=	Bank Angle
Θ	=	Inclination Angle
Ψ	=	Azimuth Angle

1.2 Abbreviations

ACM	Air Combat Maneuvers
AGARD	Advisory Group for Aerospace Research and Development
BI/CSD	Bombardier/ Canadair Defence Systems Division
BFM	Basic Fighter Maneuvers
CA	Canada
CF	Canadian Forces
CSFDR	Crash Survival Flight Data Recorder
FBW	Fly By Wire
EFCS	Electrical Flight Control System
GAF	German Airforce
GE	Germany
HT	Horizontal Tail
IABG	Industrieanlagen Betriebsgesellschaft (German Test Center)
IAS	Indicated Airspeed
MIL–Spec	Military Specification
MRCA	Multi Roll Combat Aircraft
MSDRS	Maintenance Signal Data Recording System
MTOW	Maximum Take–Off Weight
man_0243	CF–18 Maneuver Identification Number
NATO	North Atlantic Treaty Organization
NL	Netherlands
PCM	Pulse Code Modulation
PITS	Point In The Sky
RAAF	Royal Australian Air Force
RF	Rear Fuselage
SMP	Structures and Materials Panel
TAS	True Airspeed
US	United States of America
USAF	United States Air Force
VT	Vertical Tail
WG	Working Group
$WR_{R,L}$	Wing Root Right,Left

1.3 List of Symbols

T	Normalized Time
t	Time
V	Flight Speed
M_a	Mach Number
Alt	Altitude
n_x	Longitudinal Load Factor
n_z	Normal Load Factor
n_y	Lateral Load Factor
p	Roll Rate
$\dot{p}$	Roll Acceleration
p_{dot}	Roll Acceleration
q	Pitch Rate
$\dot{q}$	Pitch Acceleration
q_{dot}	Pitch Acceleration
r	Yaw Rate
$\dot{r}$	Yaw Acceleration
r_{dot}	Yaw Acceleration
Φ	Bank Angle
$\dot{\Phi}$	Rate of Change of Bank Angle
Θ	Inclination angle
$\dot{\Theta}$	Rate of Change of Inclination Angle
Ψ	Azimuth angle
$\dot{\Psi}$	Rate of Change of Azimuth Angle
ξ (X_i)	Aileron/ Flaperon Deflection
η (Eta)	Elevator Deflection
ς (Zeta)	Rudder Deflection

B_x	Bending moment
B_y	Bending moment
B_z	Bending moment

X	Axial Force
Y	Side Force
Z	Normal Force

α	Angle of Attack
β	Angle of Sideslip

C_L	Lift Coefficient
C_N	Normal Force Coefficient
C_y	Lateral Force Coefficient
C_l	Rolling Moment Coefficient
C_n	Yawing Moment Coefficient
C_m	Pitching Moment Coefficient

2. INTRODUCTION

The determination of the design maneuver loads is largely specified in regulations independently of the maneuvers or missions actually performed in operation.

For conventionally controlled Aircraft the regulations give the time history of the control surface deflections and numerically define several essential maneuver – load parameters for the determination of the design load level.

Obviously with the introduction of the fly–by–wire and/or active control technology, as well as care free maneuvering features, recent specifications no longer define the control surface deflections but rather provide the cockpit displacements of the controls in the cockpit.

This means that existing design load regulations and specifications based on conventional aircraft configurations, structural design concepts and control system technologies, may not be adequate to ensure the structural integrity of future military aircraft configurations using novel control methods, structural concepts and combat tactics.

In service, maneuvers, especially combat maneuvers, are flown in accordance with practiced rules that lead to specified motions of the aircraft. In Germany, an evaluation of operational flight maneuvers has been made for three aircraft types flown by the GAF with the aim of deriving operational loads by applying parameters measured in operational flights. This data was used as a data base. For the maneuvers evaluated, a normalization of the relevant parameters of motions was feasible, and the results could be verified in a maneuver model.

Within the scope of this evaluation, an attempt has been made to find a way of load analysis from operational maneuvers in addition to the applicable design specifications. The evaluation is based on the assumption that it should be possible to standardize the several maneuvers trained and flown by NATO Air Forces. Specifically, this means that it should be possible to find a standardized time history for each type of maneuver, which is independent of the extreme values of the relevant parameters. Based on this assumption, it was analyzed how the evaluation of structural loads could be realized after previous standardization of maneuvers taking into account the maneuver model for calculating the control surface deflections necessary for performing the maneuvers considered.

3. BACKGROUND AND STATE OF THE ART

3.1 General

In conjunction with the 65th meeting of the AGARD Structures and Materials Panel (SMP), a workshop on "Design Loads For Advanced Fighters" was held. Although several approaches for designing modern fighters were presented, no common basis for establishing the range of extreme values of design parameters could be found. The final discussions at the conclusion of the workshop compiled a list of possible follow – on actions. One of these was to evaluate and correlate design parameters. At the 66th meeting of the SMP, this topic was discussed and it was decided that the most significant aspect of establishing and correlating parameters was to allow the generation of design loads for the proper sizing of structural elements. It was postulated that analysis of operational maneuvers by the most current fighters in service would allow the extraction of critical parameters and their range of values. There was also a recognized need to determine if pilots were taking advantage of fly–by–wire (FBW) and carefree flight control concepts to attempt new types of maneuvers which could generate other load cases than those specified in the regulations now used for structural design.

At the 69th meeting of the SMP the results of analyzing some data recorded on operational F–16's in a digital recording format were presented by the US. This data was subsequently used by Germany to attempt to extract discrete maneuvers and to determine the range of parameters of interest. This effort showed that the concept was feasible. However, the data sample was too small to allow a conclusion on the general applicability of the method or to draw any conclusions on the maximum expected value of parameters or their combination for establishing design maneuvers.

It was therefore proposed that the data from GAF and USAF be supplemented with operational flight parameter data from other NATO–nations with the aim of deriving correlated design parameters for fighter aircraft as common basis for static and fatigue design.

During the 74th meeting of SMP there was an interest in this activity from at least 4 nations(US, CA, NL, GE). In the meantime recorded Flight–Test Data from Canadian CF–18 aircraft, were made available for evaluation.

The Working Group 27 "Evaluation of Loads from Operational Flight Maneuvers" was established at the 76th meeting of the SMP. Four nations (US, CA, NL, GE) are member of the Working Group. The WG27 involvement is to address the potential of recordings available and the evaluation concept to:

- Address and resolve concerns about the adequacy of current structural design loads criteria in use by the NATO military aircraft development authorities.

- Formulate a common set of design loads criteria for studying new fighter designs.

- Identify those maneuver parameters which should receive special attention in designing structures for FBW and/or carefree controlled aircraft.

- Identify design loads parameters and their extreme magnitudes that are unique to different types of missions and maneuvers.

- Improve on the methodology for analyzing and correlating operational flying with the establishment of design load parameters.

- Improve on the use of operational flight data in determining fatigue loads.

Germany, which initially proposed the method and has the established analytical capability, took a lead role in this work. Other participants provided data and collectively reviewed the analytical results, formulated conclusions and advised on the direction of the work. Canada also provided loads data on the CF–18 aircraft and calculated loads from the outputs from Germany for comparison purposes.

3.2 Technical Overview

The basic assumption of this loads process is that all operational maneuvers performed in service can be verified as a set of Standard Maneuvers (normalized parameter time histories for each independent maneuver type).

The verification of Standard Maneuvers is based on recordings of relevant maneuver parameters in service and for new tactics/ missions on special flights or simulations.

The determination of operational loads is feasible by applying the Maneuver Model.
In the Maneuver Model the time history of the control deflections necessary to perform the maneuver to be considered are calculated taking into account the aircraft basic data (see section 5.5). Boundary Conditions can also be applied depending what kind of loads are to be determined:

- for Extreme Operational Loads the Boundary Conditions for design (max. load factor, limits of flight control system/ control surface deflections etc.) are to be taken into account.

- for Fatigue Loads the values of the maneuver parameter spectra as boundary conditions are taken.

- for Loads related to the recorded parameters the recorded parameters without application of the Standard Maneuver Procedure can be taken.

For the determination of the extreme operational loads an idealization of the maneuver parameters has been performed:

- To cover the most extreme peaks of the control surface deflections possible, respectively the most extreme accelerations in roll (p), pitch (q) and yaw (r).
  This is obtained by linearization of the acceleration time history in a way to have the same response of the aircraft movement.

- To obtain a short but intensive input of control deflections at the initiation of the maneuver and a short but intensive input of control deflection at the completion of the maneuver keeping compliance with the aircraft attitude parameters for the required maneuver type.
  Between initiation and the completion of the maneuver, control surfaces should be deflected a way that aircraft accelerations are more or less constant.

These operational loads can be used for:

- The determination of the operational loads level for aircraft already designed with regard to the design load level (static and fatigue) as specified in the present regulations

- The determination of the load level for static and fatigue design for new aircraft to be developed.

The Working Group agreed on the concept to evaluate the operational maneuver parameters in three parts

I   Derivation and verification of Standard Maneuver time histories for several maneuver types

II   Definition of Maneuver Boundary Conditions
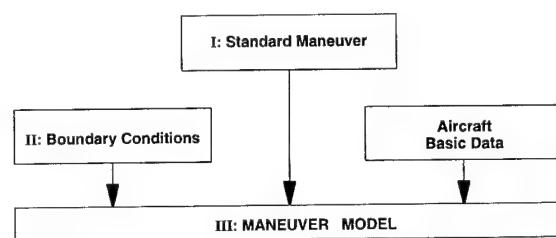
III   Verification of a Maneuver Model

Figure 3.2   Technical Program

I: The Standard Maneuver time histories are formed for identified maneuvers from operational recording by
   – Normalization of the parameter time histories
   – Idealization (linearization of accelerations)
   – Tuning (Relation of Euler angles and angular rates)

II: The Boundary Conditions for tailoring the Standard Maneuver time histories can be determined
   – from spectra of main load parameters applying, extreme value distributions
   – as stated in the requirements or aircraft specification to be applied

III: In the Maneuver Model the load parameters for operational maneuvers are determined by calculation of the control deflections to perform the maneuver time history taking into account the aircraft basic data

- Aircraft configuration

- Aircraft aerodynamic data

- Flight control system data/– gearings

- Flight conditions

The flow chart in Figure 3.2 presents the technical program.

4. OBJECTIVES

4.1 General

The general objective of Working Group 27 is to evaluate the potential of using data from operational usage data to generate parameter time histories that can be used to determine for the sizing of structural components. This general objective was translated into a terms of reference of Working Group 27 which included the following detailed objectives:

- To evaluate operational maneuver load parameters as time history for each maneuver type.

- To verify the time histories of load relevant parameters for the maneuvers performed in operation as a set of standard maneuvers. For each type of standard maneuver the normalized motion parameters are to be validated independent of aircraft type, mass configuration and flight control system.

- To derive extreme operational maneuvers and for maneuvers for fatigue from standard maneuvers of each maneuver type taking into account the mass configuration, flight condition (Ma, altitude) and the maximum control deflections.

4.2 WG–27 Task

Working Group 27 was provided with the above objectives and an approximate two year mandate to meet these objectives. This time limitation required that the objectives be prioritized so that the main issues are addressed first. In discussion, the WG formulated a set of activities that addressed the fundamental premises of the method to generate operational loads from flight parameters. These activities, in order of priority were:

- To confirm that information on a number of current operational data was available from service experience of fighter aircraft (CA, US, GE) with particular reference to load relevant parameters (nz, ny, p, q, r, Φ, Θ, Ψ).

- To validate these data on operational missions for completeness of parameters and suitability for separating them into missions and maneuvers.

- To demonstrate that standardized maneuvers derived data from different aircraft types data are essentially the same for the same real time maneuver;

- To determine alternative approaches for data analysis of load relevant parameters, particularly
  – Identification of mission/ maneuver types
  – Analysis of parameters with respect to:
    ○ extreme value distribution for static design
    ○ correlation of load relevant parameters
    ○ mean value distribution for fatigue design

- Perform a limited demonstration study using available CF–18 data and a flight test validated loads calculation process that would compare major section loads calculated using real CF–18 parametric data to those calculated using the parameters generated by a reconstitution of a standardized maneuver from F–16 as input.

- Determination and application of a maneuver model.

5. TECHNICAL APPROACH

5.1 Procedure Overview

The proposed maneuver model is one important step in the whole evaluation procedure. The flow chart in Figure 5.1 presents the general data flow and indicates the major phases of the procedure and identifies the chapters of this report.

The application of the maneuver model is based on three basic inputs:

–First: Standardized parameter time histories of different maneuver types, derived from operational maneuver types.

–Second: The boundary conditions of the selected maneuver types.

–Third: Basic aircraft data for the maneuver model calculation.

The Maneuver Model is designed specifically to calculate the control deflection time histories from the specified motion of the aircraft in the sky. After a process of verification, the control deflection and response parameter data represents the model parameters for the structural load calculation. The loads for structural components are calculated in the conventional way.
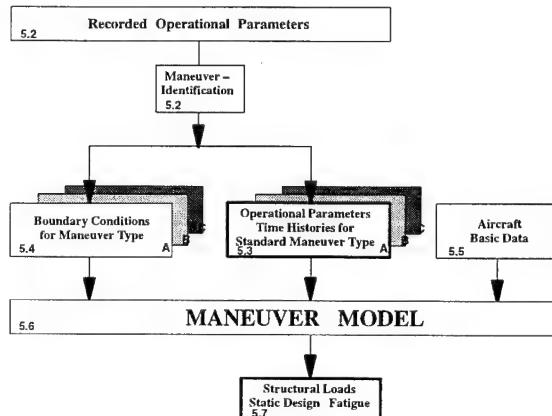

Figure 5.1 Procedure Overview

5.2 Operational Parameters

The Maneuver Model is based on the assumption that maneuvers trained and flown by the NATO Air Forces can be standardized. In practice, maneuvers, especially combat maneuvers, are flown in accordance with given, practiced rules that lead to a specified motion of the aircraft in the sky.

The standardized maneuver time history is the replacement for all operational maneuvers of the same type.

The Standardized Maneuver is obtained by normalization of amplitudes and maneuver time to make the parameters independent of mass configurations, intensity of the maneuver, flight condition, flight control system and of the aircraft type.

The goal is to find a standardized time history for each type of maneuver, which is independent of the extreme values of the relevant parameters and aircraft type.
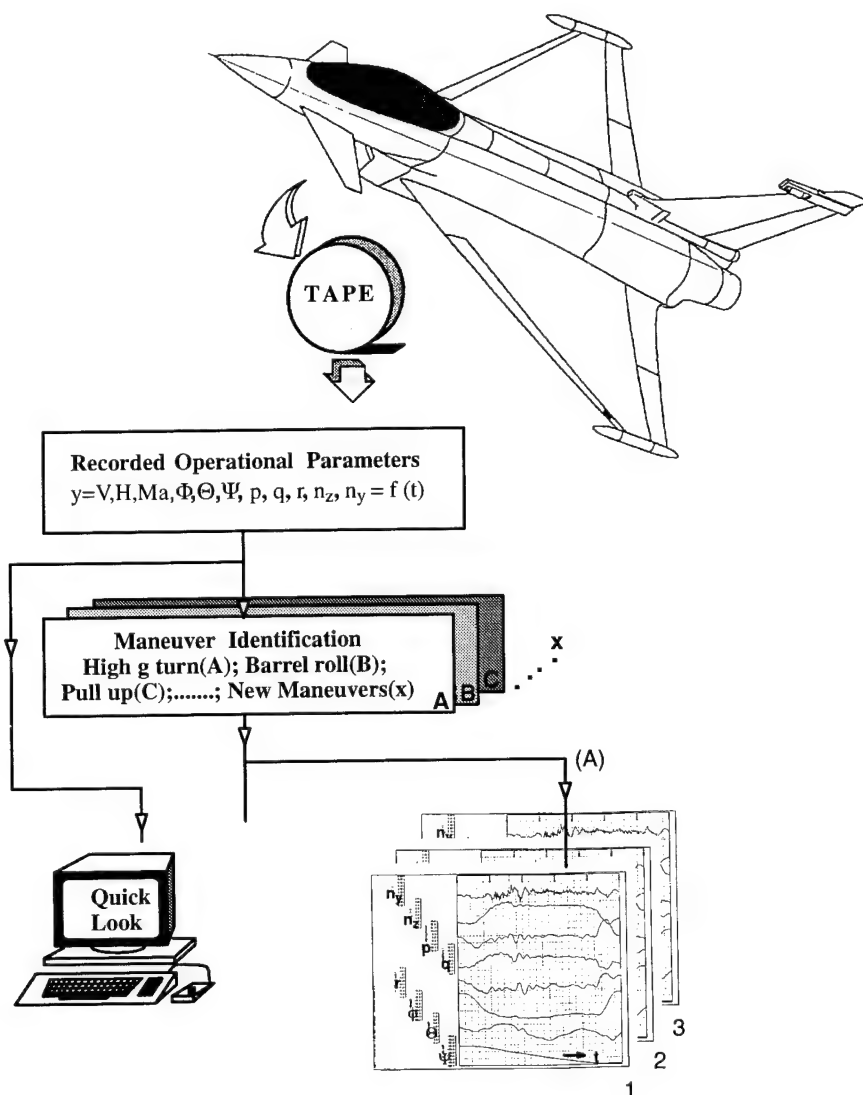
The number of parameters defining the aircraft motion should be chosen in such a way that recording and evaluation cause minimal expense.

This can be achieved by using parameters available from existing systems of the aircraft.

For identification of the flight condition for the recorded maneuvers, the parameters:

– Air speed (Mach–number), Altitude, and recording time are necessary.

– Each maneuver type must be represented by a data set of relevant parameter time histories.

– The following operational parameters are to be recorded: load factors (ny, nz), the angular rates (roll–,pitch–and yaw rate), and the Eulerian angles–$\Phi\Theta\Psi$, if available.

TAPE

Recorded Operational Parameters
$y=V,H,Ma,\Phi,\Theta,\Psi, p, q, r, n_z, n_y = f(t)$

Maneuver Identification
High g turn(A); Barrel roll(B);
Pull up(C);.......; New Maneuvers(x)

Quick Look

Plots of correlated Time Histories for several Maneuvers (in this Sketch 3 Man.) of the same Maneuvertype e.g. (A)

6

5.2.1 Maneuver Identification

The goal of the maneuver identification is to select the relevant maneuver segments from the recorded operational data base.

First: The data are checked for completeness and suit-
          ability for separating them into missions and ma-
          neuver types as shown in Figure 5.2.1 .

A maneuver is identified by comparing the observed data with the predefined maneuver characteristics as described in Maneu-ver Type Description Figure 5.2.2 .

The maneuver identification parameters are mainly load factor (n_z), roll rate (p), bank angle (Φ)

Second: The start and end time of each maneuver type are
          identified when the
          roll rate is near zero and the g is approximately 1.
          The bank angle also indicates the type of maneuver,
          i.e. full roll $\Phi \approx$ 360 degrees,
          half roll $\Phi \approx$ 180 degrees, turn < 90 degrees.
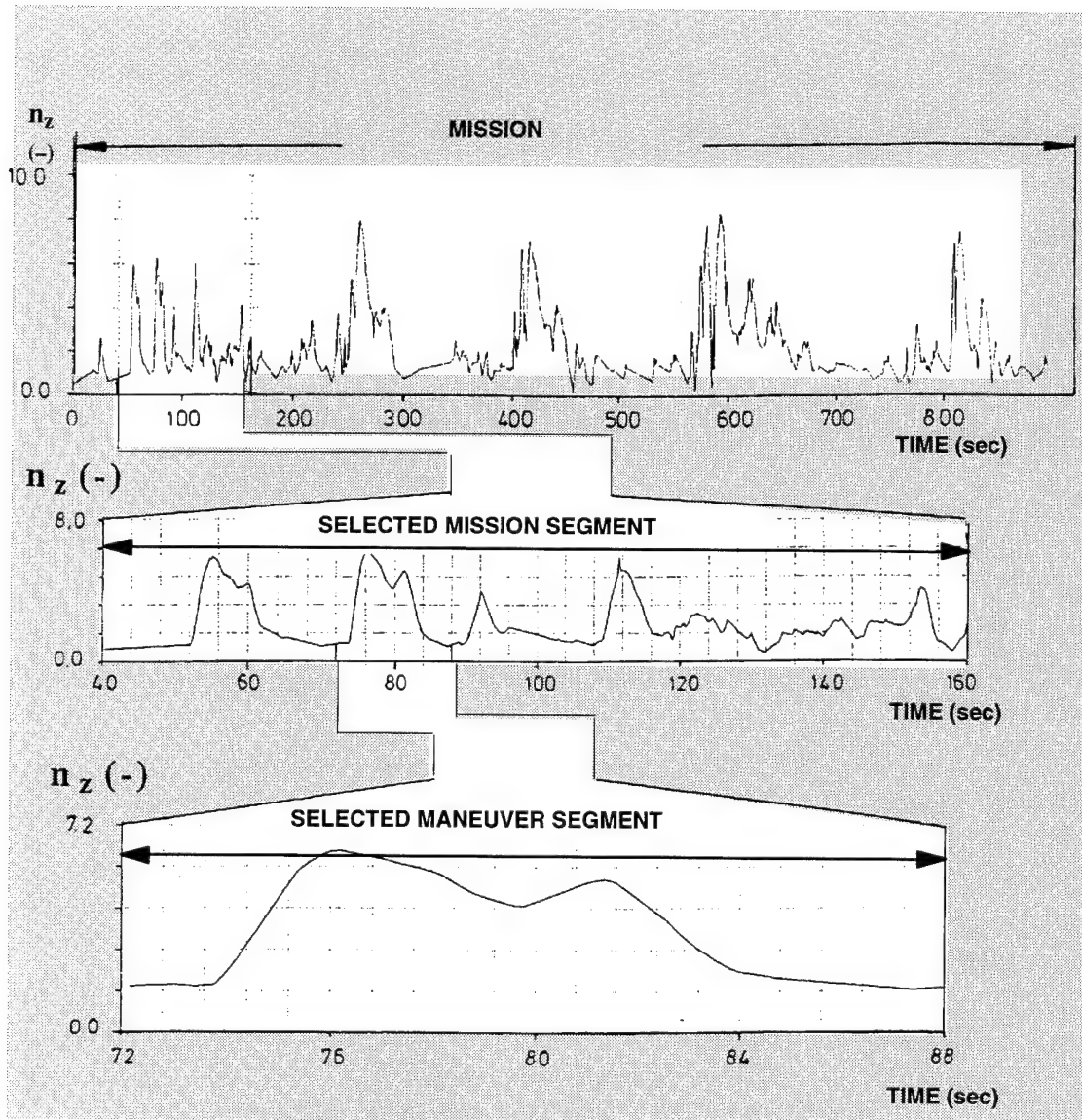
Figure 5.2.1

5.2.2 Identified Maneuver Type Time Histories

Figure 5.2.3 shows as an example for the identification of a high g turn maneuver. In this case the roll rate trace primarily defines the maneuver length.
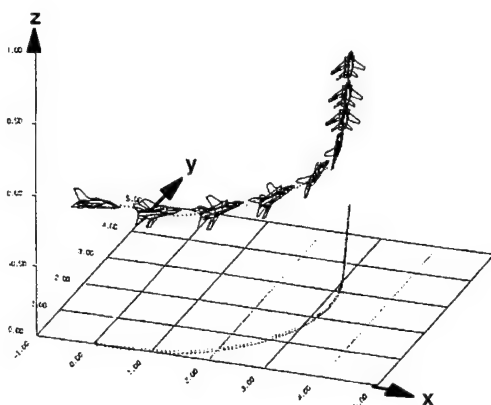
The pilot first rolls the aircraft in the direction of the turn and finally rolls it back to the wings level position. In parallel, the g rises to a peak value. The peak is held as long as desired. The g drops down from its peak as the aircraft is rolled back to the wings level.

The start and end of the maneuver are determined as follows: the maneuver starts when the first negative/ positive deflection of the roll rate trace starts and the maneuver finishes after recovering i.e. the opposite deflection of this trace, decreased to zero.

The Eulerian angels $-\Phi, \Theta, \Psi$ give the aircraft orientation with respect to the earth's coordinate system.

The bank angle values indicate the type of maneuver as defined in Figure 5.2.2 .

All recorded parameters are time related.

Movement projected on ground

Turn : $n_z \leq 2$, $p > \pm 20°/sec$, $\phi \approx 40 \div 90°$	Roll steady to bank angle, pull, the bank angle is held as long as desired, opposite roll back to level
	Roll rates of opposite sign before and after g peak
High g Turn : $n_z > 2$	Turn Maneuver
Break : $n_z > 3$	High g Turn Maneuver with g peak during initial maneuvertime
Scissors :	A series of High g Turn Maneuvers
Roll Reversal : $n_z < 2$, $p > \pm 20°/sec$, $\phi \approx 20 \div 90°$	Roll steady to bank angle, directly opposite roll back to level
High g Rolls : **(Barrel rolls)** $n_z. > 1,5$, $p > \pm 20°/sec$, $\phi_{max} \approx 360°$	Roll steady in one direction Barrel roll over top Θ rise to a positiv peak value Barrel roll under neath Θ descend to a negativ peak value
Pull sym. : $n_z. > 1,5$, $\Delta\Phi < 10°$	From $\sim$ 1g to g peak, back to $\sim$ 1g

Figure 5.2.2   Maneuver Type Description of Selected Maneuvers

First roll rate peak

n_z–trace

Opposite roll rate peak

pitch rate trace
yaw rate trace

(High g turn)

Time history of correlated operational parameters

Figure 5.2.3   Identified Time Histories

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5.3 Standard Maneuver

The standard maneuver is the second basic input of the maneuver model.

The whole evaluation is based on the assumption that it is feasible to standardize each maneuver type trained and flown by the NATO Air Forces.

This means it should be possible to find a data set of standardized time histories for each, type of maneuver, which is independent of the extreme values of the relevant parameters.
Figure 5.3 presents the overview of the standardization procedure.

Provided the operational parameter time histories of the basic

parameter are available in correct units, this procedure includes several steps:

(1) Maneuver type identification

(2) Normalization of relevant parameter time histories for a number of identified maneuvers of the same maneuver type for comparison

(3) Determination of the mean values for each relevant parameter time history of the same maneuver type

(4) Idealization and tuning of the parameter time histories

(5) Determination of the standard maneuver time histories.
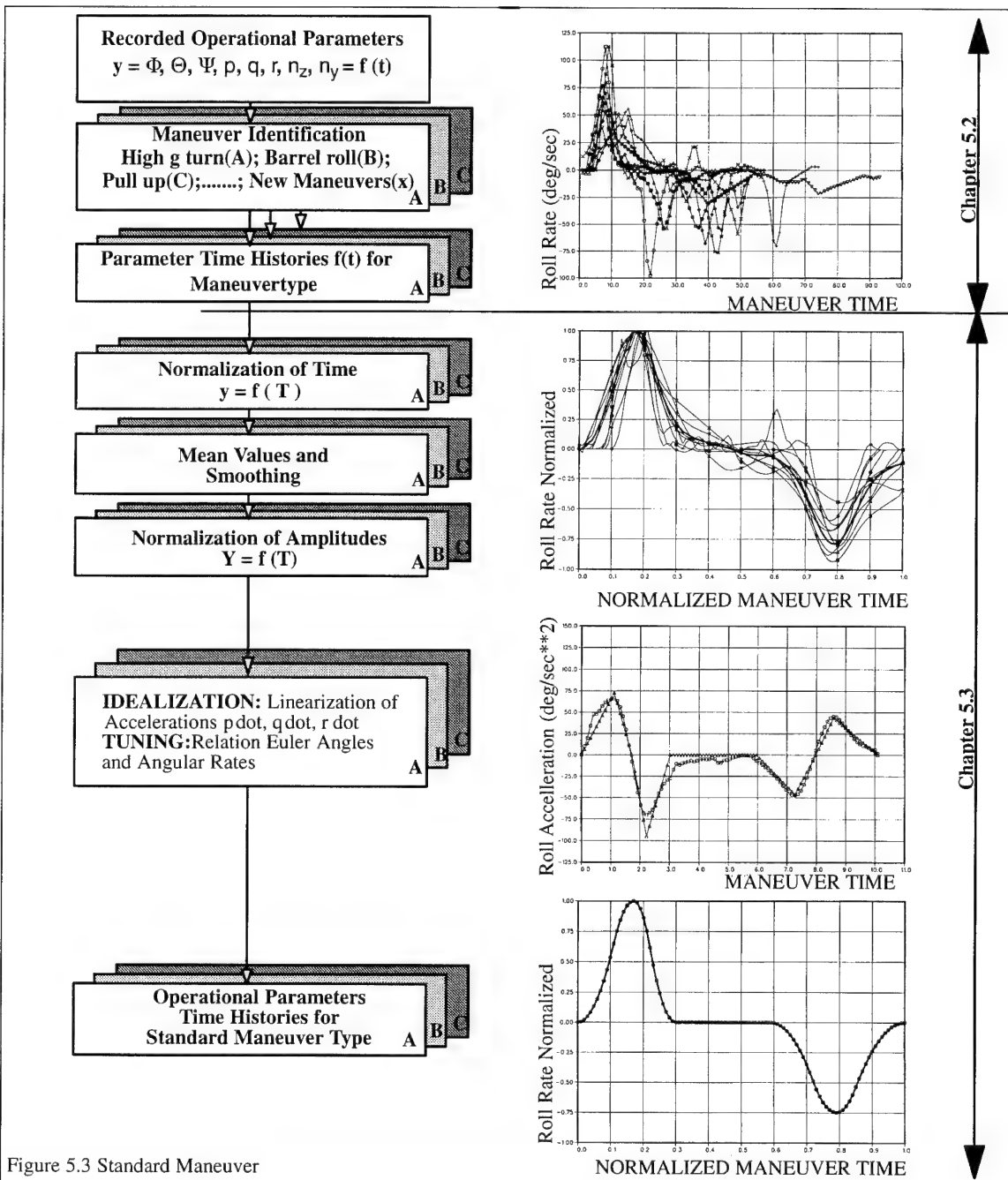
Figure 5.3 Standard Maneuver

5.3.1 Normalization

Normalization is necessary because several maneuvers of the same type are different in roll direction, amplitude of motion and in maneuver time. For the calculation of loads from operational maneuvers it is not important to separate the maneuver types into different roll directions. Therefore, maneuvers of the same type are transformed into a unified roll direction. See Figure 5.3.1.1
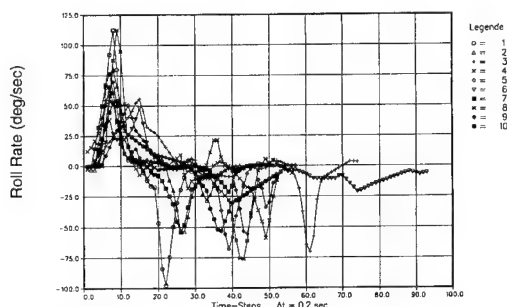

Figure 5.3.1.1

For a requisite comparison, a two – dimensional normalization is necessary.
In Figure 5.3.1.2 illustrates the basic procedure of normalization. The ordinate presents one of the parameters of motion ($y = n_y$, n_z , p , ...) for several maneuvers of the same type (y_1, y_2,.....y_n).

These parameters are normalized by relating them to the maximum values (absolute derivation from zero) which have occurred. This means the maximum value of each normalized parameter becomes in this case:

$$Y = y_1 \text{ (max)} = y_2 \text{ (max)} = + 1.0$$

The time is presented by the abscissa (t), where by the maneuver executing time is marked by t_1, t_2, ... t_n for several maneuvers. The normalization is accomplished in a way that:
- firstly, the maneuver time is chosen as the value 1.0 ($t_1 = t_2 = T = 1.0$)
- secondly, the extreme values of the relevant parameters is chosen at the same normalized time.
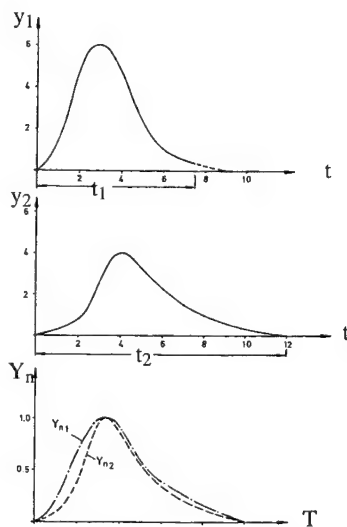

Figure 5.3.1.2   Normalization of Parameters

The time scale normalization factor for **all** correlated parameters (n_y, n_z, p, q, r, Φ, Θ, Ψ) within, for example, a High g turn was derived from the roll rate trace. See Figure 5.3.1.3.
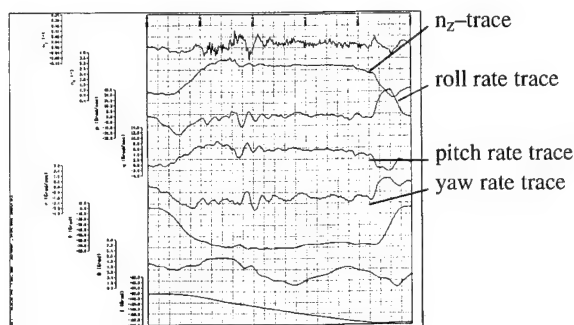

Figure 5.3.1.3 Correlated Parameters

Note: In this case the initial roll direction is negative.

In the normalized time scale, T = 0 corresponds to the time when the roll rate trace first goes negative or positive (start of the maneuver), and T = 1 corresponds to the time when the roll rate trace is back to zero after the opposite roll rate peak (finish of the maneuver). Figure 5.3.1.4 shows the normalized roll rate trace (positive roll direction)
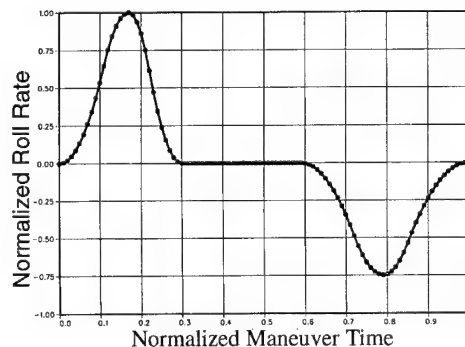

Figure 5.3.1.4

This normalization procedure is dependent on an accurate maneuver start value. (p $\approx$ 0 deg/sec)

In several cases the start values of the available time slices are very poor. (F–16 and CF–18 data)
One reason is the low sample rate of e.g. 1 or 2/sec. Recordings from Flight tests are sampled 24 times per second.
An other reason is the selected parameter threshold values of the maneuver reduction and identification process, combined with a low sample rate. Figure 5.3.1.5
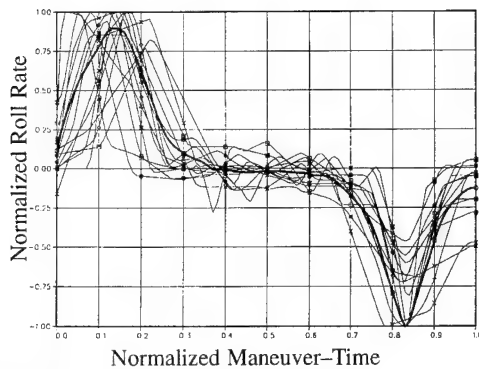
10

Figure 5.3.1.5

For these cases an upgraded normalization procedure, derived from the basic procedure, is used.

The estimated time of a high g turn ($te_i - ts_i$) as shown in Figure 5.3.1.3 and 5.3.1.6 had a very high correlation with the difference between the time of the first roll rate peak ($t1_{pi}$) and the time of second roll rate peak ($t2_{pi}$). This time ratio is very important for the normalization procedure.
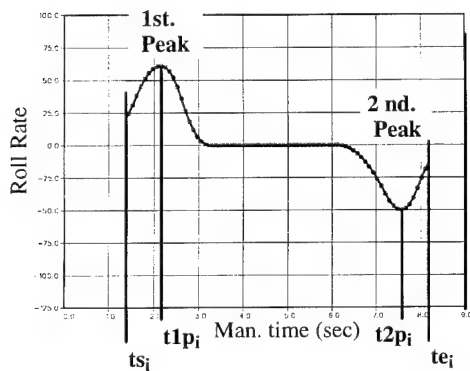

Figure 5.3.1.6

The time transformation from real time into normalized time requires several steps:

Step 1: Harmonization of maneuver time ratios
For the comparison of the parameter traces, a harmonization of the maneuver time ratios is necessary.

The harmonization is given by:

$$tr_i = \frac{t2p_i - t1p_i}{te_i - ts_i} \quad < 1$$

$$tsf_i = \frac{tr_i}{tr_{min}} \quad \geq 1$$

$$tm_i = (te_i - ts_i) \times tsf_i$$

$$trn_i = \frac{t2p_i - t1p_i}{tm_i}$$

$$tne_i = ts_i + tm_i$$

now, all time ratios (trn_i) are equal and the new maneuver time end values (tne_i) are determined. See Figure 5.3.1.7
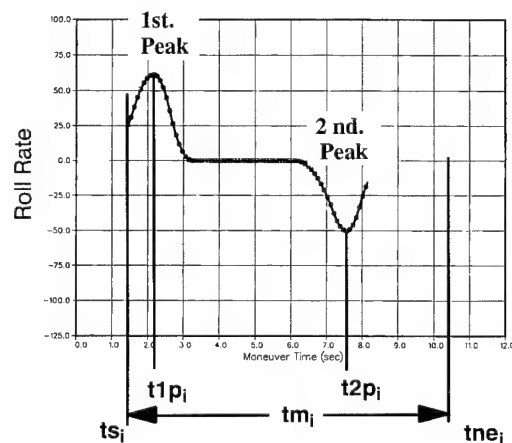

Figure 5.3.1.7

j	= 1,2...101	number of step
i	= 1,2...n	number of the same maneuver type
ts_i	=	maneuver time start value
te_i	=	maneuver time end value
tne_i	=	new maneuver end value
tm_i	=	new whole maneuver time
tsf_i	=	time scale factor
$t_i(j)$	=	maneuver time
$T(j)$	=	normalized time
tr_i	=	time ratio
tr_{min}	=	lowest ratio
trn_i	=	new ratio

Step 2: Shifting of Traces

A new interpolation of 101 time steps for each of the correlated parameter time histories(n_y, n_z, p, q, r, Φ, Θ, Ψ) for all maneu‒vers of the same type is necessary.

After the interpolation the roll rate traces were shifted in a way (between ts_i and tne_i), that all elected 1st peaks coincided at the same **time step.**

Figure 5.3.1.8 presents the comparison of the shifted roll rate traces versus normalized time (101 time steps) for the selected high g turn maneuvers.
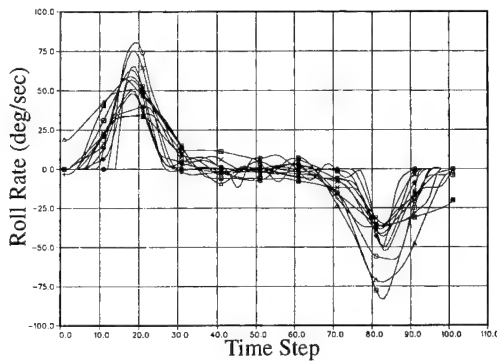
Figure 5.3.1.8

Note:

The amplitudes of the traces are not normalized. All correlated parameters are shifted parallel in the similar way

Step 3: Normalization

The transformation into normalized time is given by

$$T(j) = \frac{t_i(j)}{tm_i}$$

The amplitudes of the traces are normalized individually. Each value of the trace is divided by its absolute deviation value from zero, therefore, all normalized amplitudes will fall between ± 1.

Figure 5.3.1.9 shows the results of the new "peak to peak" normalization procedure.
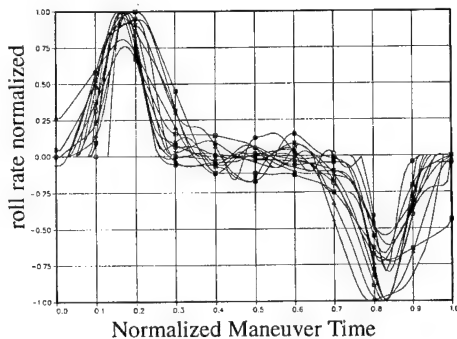

Figure 5.3.1.9

The application of the two‒dimensional normalization proce‒dure is very helpful for the comparison of maneuver time histo‒ries.

In this normalized form, all parameter time histories are inde‒pendent of the aircraft type.

This is a very important point for the application of the maneu‒ver models, as discussed later.

The normalized values <u>cannot</u> be used for any calculations of loads.

Therefore, a denormalization or reconstitution of the normali‒zed parameters for amplitudes and time is necessary for use in loads calculations.

5.3.2 Mean‒Values

After normalization of the maneuver time, for all selected ma‒neuvers of the same type, the extreme values of the relevant parameters coincide at the same normali‒zed time and each parameter time history contains 101 time steps, independent of its individual maneuver length.

This is the basis for calculating the arithmetic mean values for each of the 101 time steps.

Figure 5.3.2.1 presents the comparison of <u>non</u>‒normalized roll rate traces versus normalized time for the selected high g turn maneuvers. The roll rate is a good example for all relevant pa‒rameters.
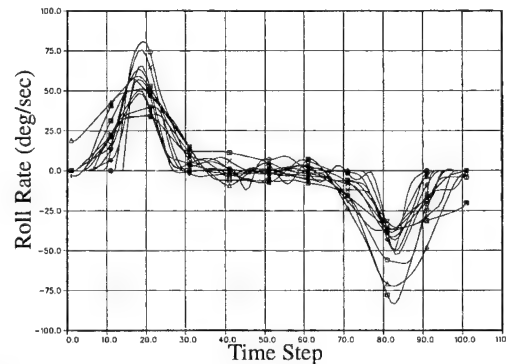

Figure 5.3.2.1

Note: The amplitudes for the mean value calculation are not normalized.

The mean value is defined by:

$$Ym(j) = \frac{\sum\limits_{i=1}^{n} Y_i(j)}{n}$$

n =   *number of maneuver of the same type*

j =   *1 ÷ 101 time steps*

$Y_i(j)$ =   *relevant parameter*

$Ym(j)$ =   *mean value*

The mean values of all parameters have been formed in combination by smoothing of the time history.

For the plot comparison, a normalization of the amplitudes is necessary.

Figure 5.3.2.2 presents the comparison of normalized roll rate and mean value versus normalized time for several high g turn maneuvers.
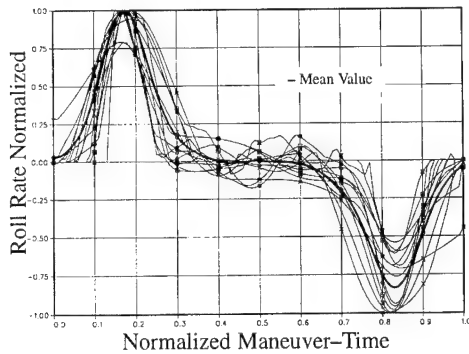

Figure 5.3.2.2

For demonstration of the normalized parameters and the formed mean values the results are plotted for high g turn and barrel roll in Chapter 6.1.3.3 ÷ 6.2, A–1 ÷ A–27

5.3.3 Idealization

The mean value traces represent a good estimation of the relationship between the selected parameters during a maneuver (e.g. high g turn).

For the compensation of any minor errors by the mean value calculation and for reasons of compatibility, the mean values have to be idealized and tuned.

The Interpretation of "idealized and tuned" as follows:

For the idealization, the computer performed the calculation in three steps.

In the first step, the following parameters were calculated:
The three angular accelerations $\dot{p}$, $\dot{q}$ and $\dot{r}$ by differentiating the three angular rates p (roll), q(pitch) and r (yaw) with respect to maneuver time. The differentiation was given by:

$$\dot{y} = \frac{\Delta y}{\Delta x}$$

In the second step, the acceleration traces $\dot{p}$, $\dot{q}$, $\dot{r}$ were replaced by linearized traces with respect to the zeros of the traces and extreme values of $\dot{p}$, $\dot{q}$, $\dot{r}$ and the corresponding extreme values of roll–, pitch– and yaw rate.

Figure 5.3.3.1 presents the comparison of derived roll acceleration trace and idealized trace versus maneuver time for a high g turn maneuver.
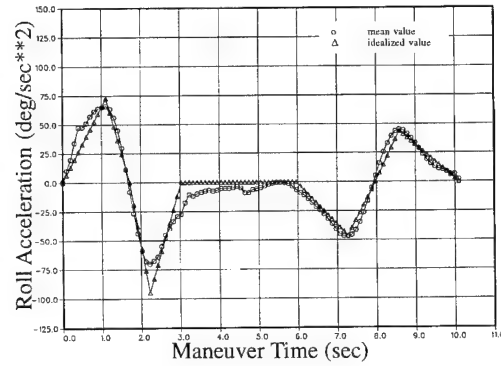

Figure 5.3.3.1

In the third step, the three angular rates –roll, pitch and yaw were recalculated by integrating the idealized values of the three angular accelerations – $\dot{p}$, $\dot{q}$ and $\dot{r}$.

For the reasons of compatibility, the idealized data have to be tuned, that means the relation between the three Eulerian angles $-\Phi$, Θ, Ψ and the angular rates p, q, r is verified with the equations:

$$\begin{aligned}
p &= \dot{\Phi} - \dot{\Psi} * \sin\Theta \\
q &= \dot{\Theta} * \cos\Phi + \dot{\Psi} * \sin\Phi * \cos\Theta \\
r &= -\dot{\Theta} * \sin\Phi + \dot{\Psi} * \cos\Phi * \cos\Theta
\end{aligned}$$

The result is the standardized maneuver.

Figure 5.3.3.2 presents the idealized and tuned –standardized– traces of the three angular rates for a high g turn maneuver. (normalized)
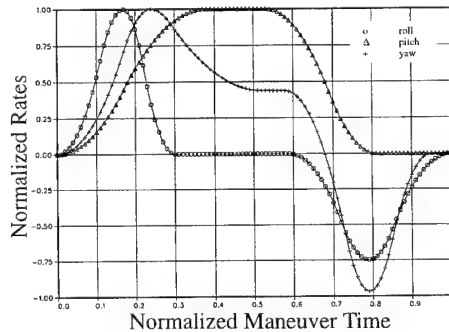

Figure 5.3.3.2

For each type of standardized maneuver the normalized motion parameters are independent of aircraft type, mass configuration and flight control system.

5.4 Boundary Conditions

Boundary Conditions have to be determined as the main input for the application of the maneuver model defining the load level. This is necessary for the determination of the extreme operational maneuvers and consequently for the verification of the design loads. For example, the parameters to be defined for a operational maneuver are:

- Design Maneuvers

    a) the shortest maneuver time (t_{Man} =min) realizable by the control system and the aerodynamic limits

    b) the maximum vertical load factor (n_z) for the maneuver to be considered

    c) the maximum lateral load factor (n_y)

    d) the maximum bank angle (Φ) for the maneuver to be considered

These boundary condition parameters can be derived from spectra of main load parameters by applying extreme value distributions, an example is shown in Figure 5.4

If no spectra are available the main load parameters stated in the Design Requirements
(MIL–Spec) e.g. n_z, Φ can be applied.

- Fatigue Maneuvers

    All the main load parameters can be taken from the related spectra available.
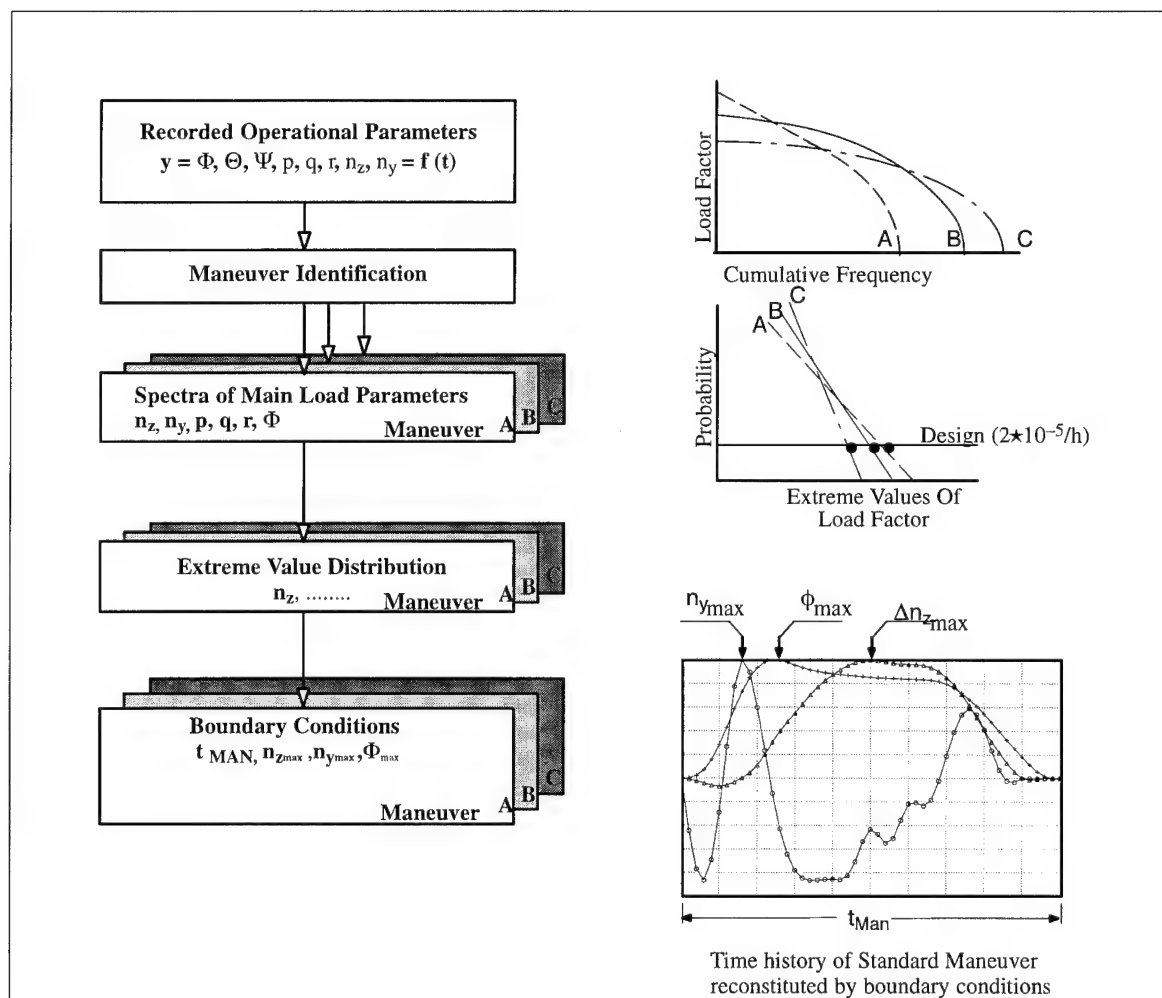

Figure 5.4   Boundary Conditions for Design Maneuvers

5.5 Aircraft Basic Data

Aircraft basic data is also the inputs for the maneuver model and is required to perform the reconstitution from the standardized maneuvers.

1. For calculation of the control deflections necessary to generate the parameter time history, the following aircraft basic data are needed:

- Aircraft configuration
  - geometric data
  - operational mass
  - inertia properties

- Aerodynamic data set for the aircraft
  - C_L, $C_m = f(\alpha)$, Cy C_l, $C_n = f(\beta,\alpha)$

- Flight Control System Data
  - for conventionally controlled aircraft mechanical gearings / limits
  - for active controlled aircraft Flight Control Law (EFCS)

- Engine Data
  - Thrust

- Flight Condition
  - airspeed, Ma
  - altitude

2. For calculation of structural loads on aircraft components, the following data are needed:

- aerodynamic data set for the components to be considered (Wing, Horizontal Tailplane, ...)
- mass data for the components to be considered

5.6 Maneuver Model

The maneuver model process is shown in Figure 5.6 as a flow chart. As input, standardized parameters are used. First, the boundary conditions have to be determined. For example, for a high g turn, the following is required:

- maneuver time, T_{Man}
- load factors, n_y, n_z
- bank angle, Φ

Using the standardized parameters the reconstitution into real time is performed. In order to perform the response calculation in the conventional manner, the control deflections are necessary and can determined as follows:

- roll control	ξ	by applying roll– and yaw equations
- pitch control	η	using the pitch equation (taking into account the symmetrical aileron deflection: if existing)
- yaw control	ς	by applying sideslip– and yaw equations

The response calculation is done for real time conditions, but for the purpose of checking the results with respect to the standardized maneuvers, the response parameters are normalized. In a comparison of the parameters between input and output of the maneuver model, the standardization is checked. In the case of confirmation the conformity of the main parameters of the response calculation with the standardized parameters, the output–parameters are considered to be verified. These verified data represent the model parameters for structural load calculation.

Application of the Maneuver Model

The application of the maneuver model is feasible for the determination of loads in general

- **for Extreme Operational Loads / Limit Loads**
  taking into account the boundary conditions for design
  - limits of flight control system
  - minimum of maneuver time T_{MAN}
  - maximum of load factors n_z, n_y
  - maximum of bank angle Φ of the maneuver to be considered

- **for Fatigue Loads**
  by building a usage spectrum made up of reconstituted standardized maneuvers.

- **for Loads related to the recorded parameters**
  taking into account the recorded parameters directly without application of the standardization procedure (Normalization, mean values and smoothing, tuning idealization) and without boundary conditions.

Only for the calculation of the control deflection necessary to perform the maneuver
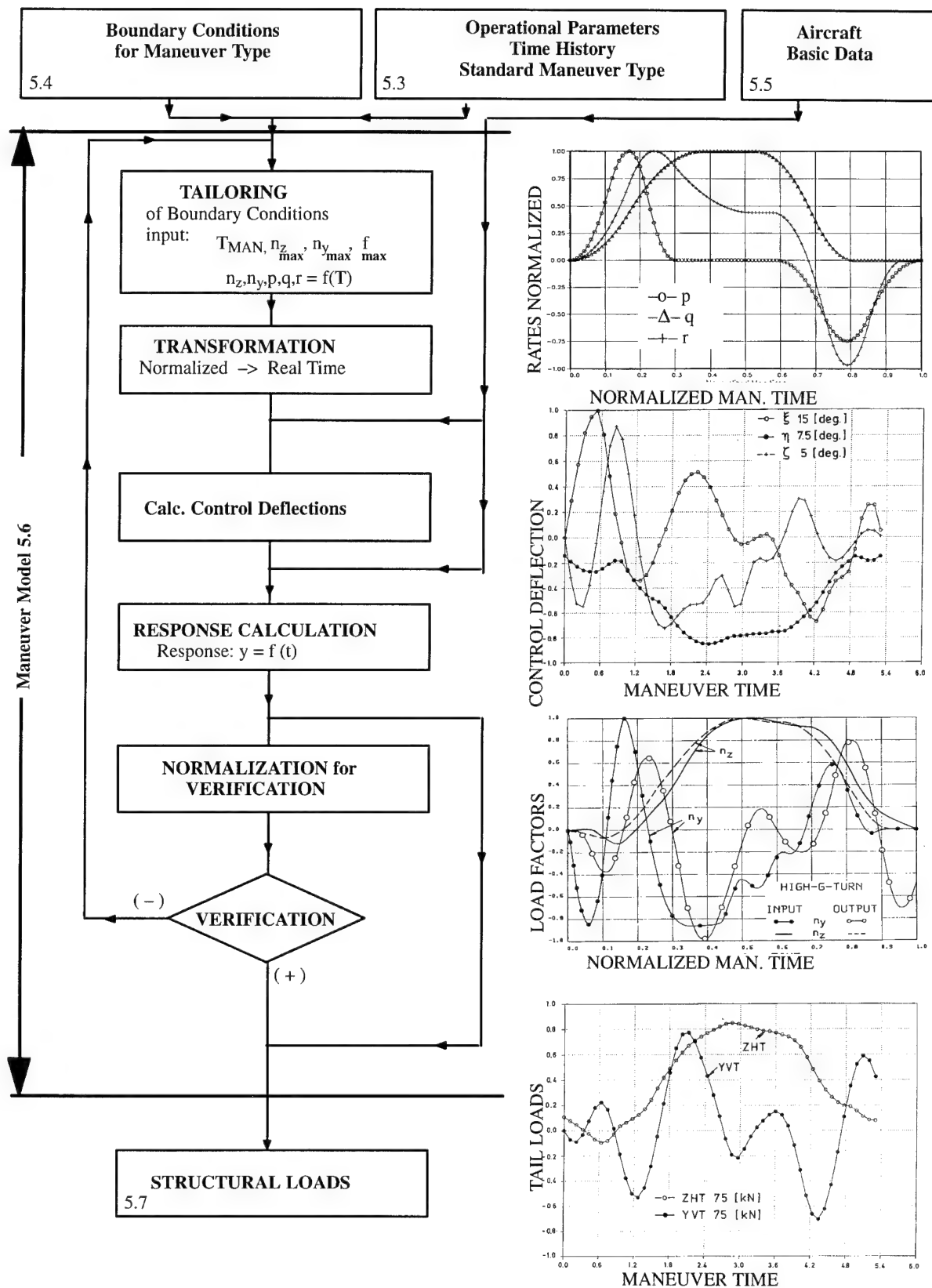
Figure 5.6   Maneuver Model

The flowchart and graphs contain the following text:

Top boxes:
- Boundary Conditions for Maneuver Type — 5.4
- Operational Parameters Time History Standard Maneuver Type — 5.3
- Aircraft Basic Data — 5.5

Flowchart (Maneuver Model 5.6):

TAILORING
of Boundary Conditions
input: $T_{MAN}, n_{z_{max}}, n_{y_{max}}, f_{max}$
$n_z, n_y, p, q, r = f(T)$

TRANSFORMATION
Normalized $\rightarrow$ Real Time

Calc. Control Deflections

RESPONSE CALCULATION
Response: $y = f(t)$

NORMALIZATION for VERIFICATION

VERIFICATION (−) (+)

STRUCTURAL LOADS
5.7

Graphs:

RATES NORMALIZED vs NORMALIZED MAN. TIME
—o— p
—Δ— q
—+— r

CONTROL DEFLECTION vs MANEUVER TIME
—o— ξ 15 [deg.]
—•— η 75 [deg.]
—•— ζ 5 [deg.]

LOAD FACTORS vs NORMALIZED MAN. TIME
n_z
n_y
HIGH-G-TURN
INPUT   OUTPUT
n_y —•—   —o—
n_z —   - - -

TAIL LOADS vs MANEUVER TIME
ZHT
YVT
—o— ZHT 75 [kN]
—•— YVT 75 [kN]

6.0 EVALUATION

The tasks of the Working Group 27 were:

1. Collect operational data from a variety of NATO opera-
   ted fighter aircraft;

2. Evaluate this data for completeness for use in this study

3. Use the operational data base to show that the normali-
   zation of the relevant parameters of motion of disparate
   aircraft is essential the same for identical maneuvers

4. Demonstrate that representative loads can be derived
   through reconstitution of these normalized parameters
   using the aircraft specific aerodynamic and control law
   data.

To reduce the work package and to meet the time restraints of
WG.27, this exercise was limited to two maneuvers, namely:

   – High g turn
   – Barrel roll

In practice, difficulties with the loads processing did not allow
the barrel roll to be calculated within recourse and time limita-
tion of this program.

For the Same Aircraft Type

The normalized CF–18 standard maneuver was be reconstituted
to real time using the CF–18 performance data and major section
loads were be calculated for one selected maneuver of the
CF–Aircraft–Data recordings.

These calculated values were then compared to the existing re-
corded values of the selected maneuvers
   a) for maneuver parameters
   b) for major section loads

In case of agreement the approach can be considered as verified
for the same aircraft.

For Disparate Aircraft Type

Demonstration of the application of the standard maneuver time
histories process for a disparate aircraft has been performed as
follows:

   – Standard Maneuver Time History from the F–16 will be
     reconstituted to real time using the CF–18 performance
     data for one selected maneuver of the CF–Aircraft–Data
     recordings.

   – For these reconstituted parameters in real time history
     the major section loads will be calculated applying the
     Canadian CF–18 loads model.

These calculated values will be compared to the existing recor-
ded values of the selected maneuvers

   a) for maneuver parameters

   b) for major section loads

That means the standard maneuver time history reconstituted to
real time, using the aircraft performance data to be considered,
is applicable independent of the aircraft type.

The procedure is shown in Figure 6.0
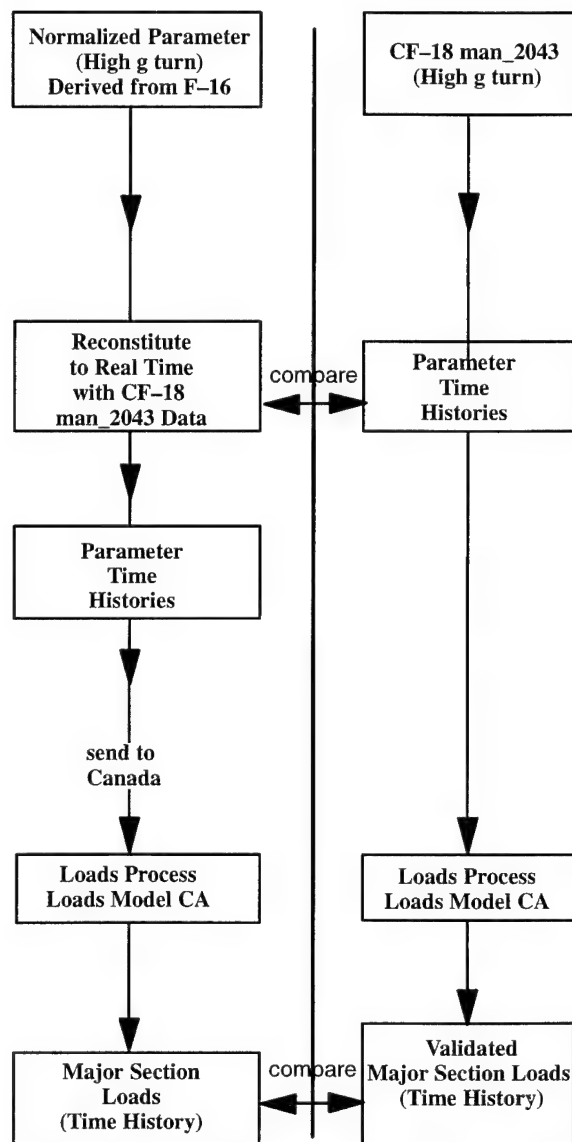
Figure 6.0   WG.27 – Procedure

6.1 Operational Data Base

The data base contains operational flight maneuver parameter data from NATO aircraft for which recorded data were readily available. These data include relevant operational parameters recorded from modern fighter of several NATO nations. The data were recorded during normal operations (service data), special flight tests and simulations of several maneuvers respectively for selected maneuvers.

Table. 6.1 summarizes the data base available to WG.27 .

6.1.1 Identified Maneuvers

From the available data base, the data were broken down into different types of maneuver.

A logic identification process is used to separate the recorded data into maneuver types, as described in 5.2.1 .

Table 6.2 shows the type and number of identified maneuvers depending on the aircraft type.

RECORDED DATA AVAILABLE						
	GAF				USAF	CF
Aircraft Type / Kind of Data	Alpha– Jet	F–4F	MRCA	JF–90	F–16	CF–18
Flight Test f or Specific Maneuvers	x	x	x			x
Service Data					x	x
Simulation for Specific Maneuvers		x		x		

Table 6.1   x)   available

Nation	GAF					USAF	CF
	A–Jet	F–4F	F–4F*	MRCA	JF–90*	F–16	CF–18
Break	5	1	3	5	6	–	–
Barrel roll	8	6	8	5	16	11	9
Full aileron reversal	–	10	–	–	5	–	–
High g roll	4	7	4	2	7	–	–
High g turn	4	7	4	2	7	21	15
Roll	–	–	–	–	–	–	131
Rolling entry a. pull out	4	7	–	–	6	–	183
Roll reversal	–	–	–	–	–	11	–
Scissors	4	2	4	4	–	13	–
Slice	4	–	2	2	–	–	–
Turn	–	–	–	–	–	7	45
Pull	–	–	–	–	–	3	6
Push	–	–	–	–	–	–	3

Table 6.2

* Simulation

Aircraft–type description (three–view drawings) is given in chapter 11

6.1.2 State of the Evaluation

For six different NATO–aircraft operational recordings have
been evaluated.
Table 6.3 presents the state of the evaluation.

STATE OF THE EVALUATION								
	GAF					USAF	CF	
	Flight Test			Simulation		Service Data		Flight test
Aircraft Type	Alpha–Jet	F–4F	MRCA	F–4F	JF–90	F–16	CF–18	CF–18
Maneuver–identification						x	x	x
Normalized Time Histories	x	x	x	x	x	x	x	x
Standard Maneuver	x	x	x	x	x	x	x	x
Spectra for Main Load Parameters					x	x		
Boundary Conditions		x						
Aircraft Basic Data		x						
Application Maneuver Model		x						
Application WG–27 Model						x	x	

Table 6.3

The crosses are indicating the basic steps of the evaluation pro-
cedure covered in this study.

Table 6.4 shows the Standard Maneuvers that have been derived
from the available data base.

STANDARD MANEUVERS							
	GAF					USAF	CF
	Flight Test			Simulation		Service Data	
Aircraft Type	Alpha–Jet	F–4F	MRCA	F–4F	JF–90	F–16	CF–18
Standard Maneuver Type	Number of operational Maneuvers (Data Base)						
High g turn	4	7	2	4	5	10	14
Barrel roll	4	3	–	–	–	3	7

Table 6.4

These standard maneuver types are the basic units for
the application of the maneuver model.

6.1.3 GAF – Aircraft – Data

6.1.3.1 Data Recording System
Maneuver–Flight–Testing (F.T.)
These data were recorded by an on –board PCM–data acquisi-
tion–system used for test purposes at the German Air Force Test
Center.
The recorded parameters and the related sample rates are given
in Table 6.5

Simulation of Maneuvers (Sim.)

The data have been taken direct from the simulator at IABG.
(German Test Center)

6.1.3.2 Purpose of Recording

The objective of the maneuver flight testing was to obtain data
describing the movement of the aircraft in the air during opera-
tional maneuvers as practiced by the German Air Force (GAF).
**The movement is being described by recording flight me-
chanical parameters as follows:**
Attitudes   : bank–, pitch–, heading angle
Rates   : roll rate, pitch rate, yaw rate
Load Factors : n_x, n_y, n_z,
Angle of attack α
Angle of sideslip β

Data was gathered for 8 operational maneuvers
– High – g – turn
– Barrel roll (over the top) (underneath)
– Break
– High – g – roll
– Slice turn
– Scissors
– Full aileron reversal
– Rolling entry and pull out

Flight Conditions
– Altitude 20,000 ft
– Ma = 0.9

Requirements for maneuver execution
– Each maneuver type was performed at least six times, at
least three maneuvers for each maneuver type by one pilot
and three by another one.
– The sequence of the maneuvers was performed such that
between the single maneuvers a recovery to the initial flight
condition was required.
– To simulate real operational conditions, a second
aircraft– as enemy aircraft– was used.

Sample Rate					
	F–4F		**Alpha Jet**	**MRCA**	**JF–90**
	F.T.	Sim.	F.T.	F.T.	Sim.
Flight condition					
Flight Speed V, Ma	8/sec	24/sec	8/sec	4/sec	24/sec
Altitude H	8/sec	24/sec	8/sec	2/sec	24/sec
Parameters needed as time history					
Roll rate p	8/sec	24/sec	8/sec	32/sec	24/sec
Pitch rate q	8/sec	24/sec	8/sec	32/sec	24/sec
Yaw rate r	8/sec	24/sec	8/sec	32/sec	24/sec
load factor n_x	8/sec	24/sec	8/sec	32/sec	24/sec
load factor n_y	8/sec	24/sec	8/sec	32/sec	24/sec
load factor n_z	8/sec	24/sec	8/sec	32/sec	24/sec
Additional parameters					
Attitudes					
Bank Φ	8/sec	24/sec	8/sec	8/sec	24/sec
Inclination Θ	8/sec	24/sec	8/sec	8/sec	24/sec
Heading Ψ	8/sec	24/sec	8/sec	8/sec	24/sec
Control surface deflection					
Aileron ζ	8/sec	24/sec	8/sec	32/sec	24/sec
Elevator η	8/sec	24/sec	8/sec	32/sec	24/sec
Rudder δ	8/sec	24/sec	8/sec	32/sec	24/sec

Table 6.5 Recorded Parameters

6.1.3.3 GAF – Normalized Time Histories

6.1.3.3.1 GAF – F–4F High g turn

Parameter Comparison of Normalized Mean Values

Legend

o = nz Load Factor
Δ = Roll Rate
+ = Pitch Rate
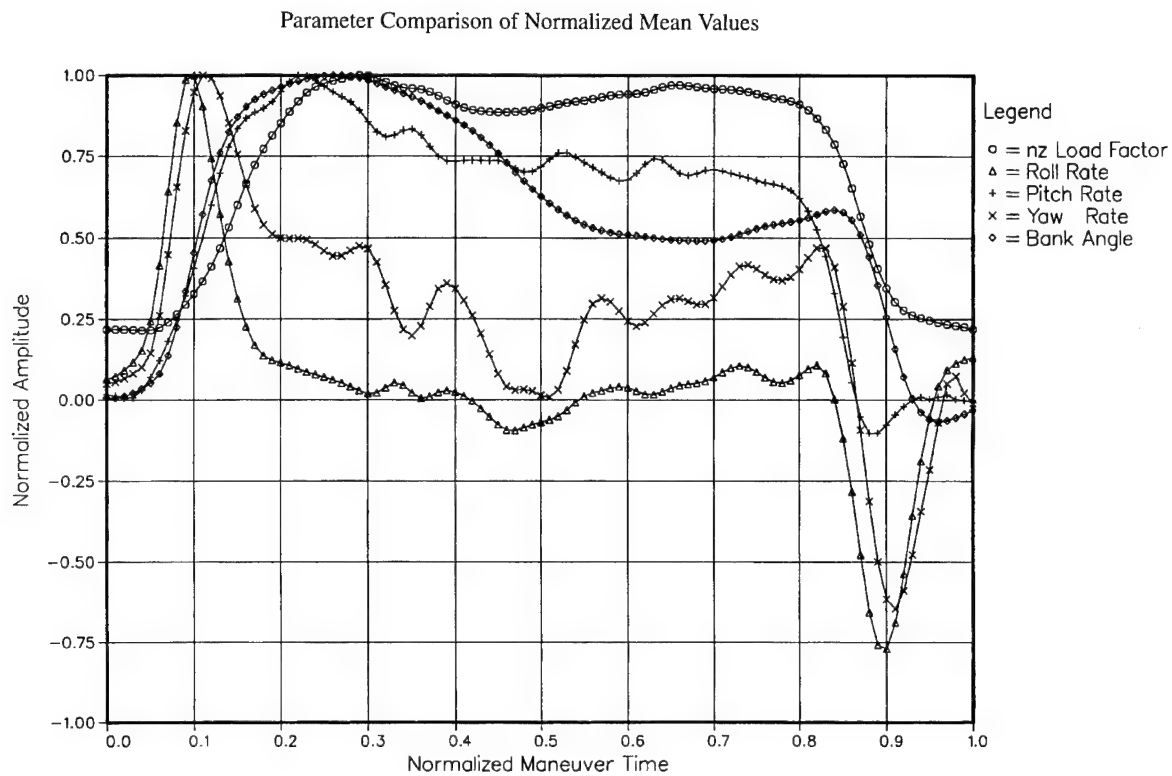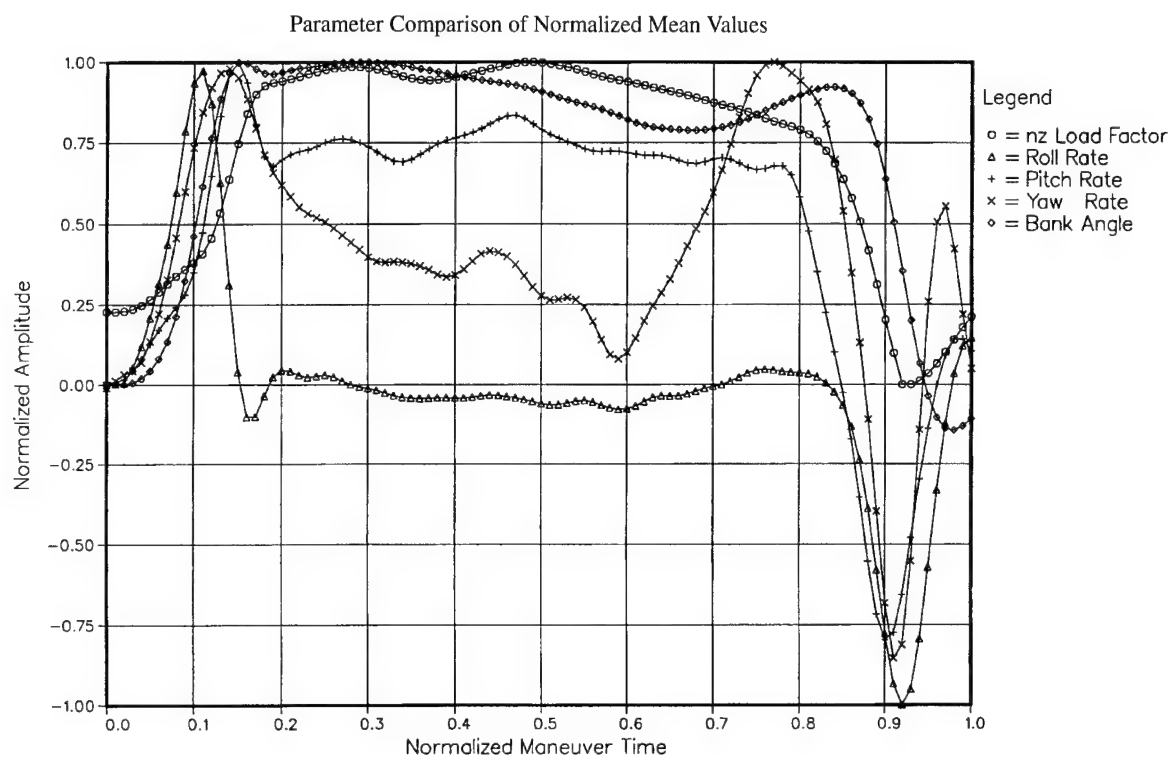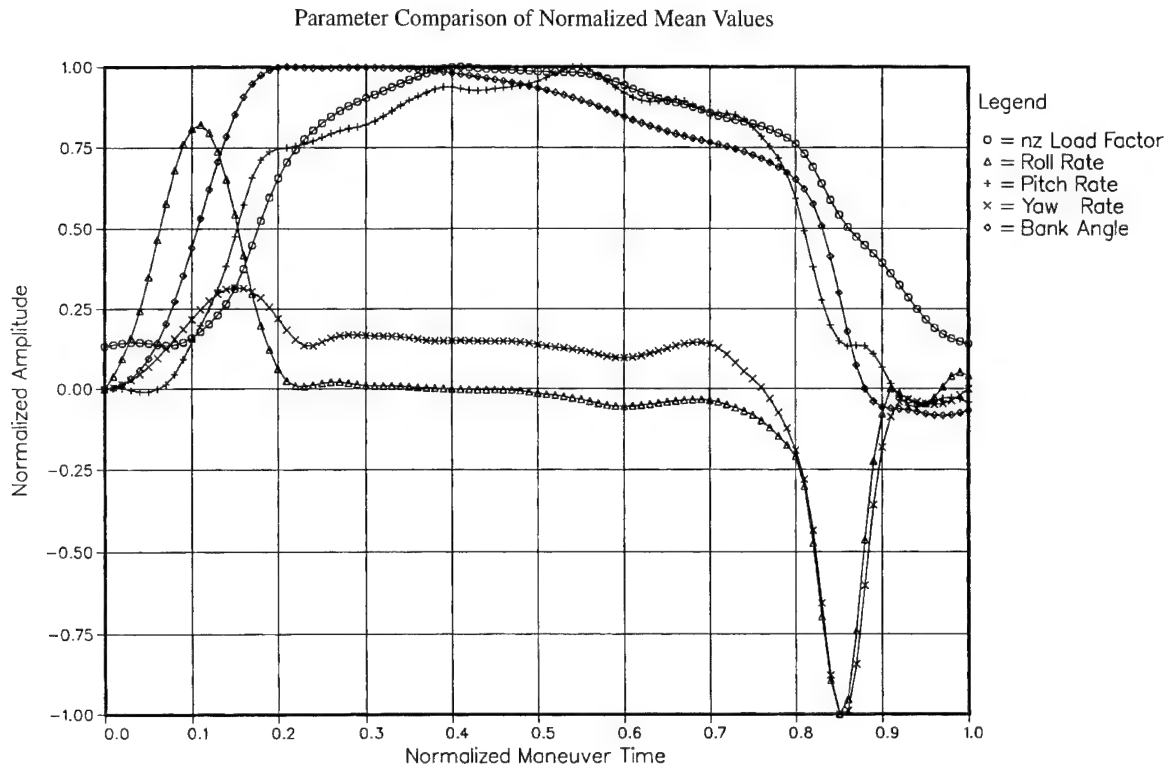× = Yaw Rate
◊ = Bank Angle

Maneuver Time (sec)	Normal Load Factor n_z (–)	Roll Rate (deg/sec)	Pitch Rate (deg/sec)	Yaw Rate (deg/sec)	Δ Bank Angle (deg)	Maneuver Identification Number
8.100	4.392	118.31	18.887	5.213	87.578	1
7.500	4.635	126.23	22.084	7.002	84.939	2
8.800	4.580	75.84	11.743	3.008	88.333	3
8.100	4.292	77.47	9.957	3.500	86.708	4
7.800	4.770	155.16	16.146	7.110	88.962	5
7.000	5.042	69.31	10.830	2.899	75.495	6
9.400	4.547	75.36	9.501	2.873	86.037	7
8.1	4.61	99.669	14.164	4.515	85.436	mean

Recorded extreme values of single maneuver parameters and formed mean values

For demonstration of the normalized parameters
and the formed mean values the results are plotted
in Annex A–1 ÷ A–3

6.1.3.3.2 GAF – Alpha–Jet High g turn
Maneuver Comparison

Parameter Comparison of Normalized Mean Values

Legend

o = nz Load Factor
Δ = Roll Rate
+ = Pitch Rate
× = Yaw   Rate
◇ = Bank Angle

Maneuver Time (sec)	Normal Load Factor n_z (–)	Roll Rate (deg/sec)	Pitch Rate (deg/sec)	Yaw Rate (deg/sec)	Δ Bank Angle (deg)	Maneuver Identification Number
21.00	4.889	96.50	12.172	3.429	84.373	1
20.00	5.038	87.77	13.367	4.446	86.793	2
25.00	4.301	37.19	9.012	2.388	83.010	3
28.00	4.745	53.68	13.206	2.578	82.878	4
23.50	4.743	68.785	11.939	3.210	84.264	mean

Recorded extreme values of single maneuver parameters and formed mean values

For demonstration of the normalized parameters
and the formed mean values the results are plotted
in Annex A–4 ÷ A–6

6.1.3.3.3 GAF – MRCA High g turn
Maneuver Comparison

Parameter Comparison of Normalized Mean Values

Recorded extreme values of single maneuver parameters and formed mean values

Maneuver Time (sec)	Normal Load Factor n_z (–)	Roll Rate (deg/sec)	Pitch Rate (deg/sec)	Yaw Rate (deg/sec)	Δ Bank Angle (deg)	Maneuver Identification Number
24.00	5.432	95.33	14.42	7.343	91.333	1
23.00	3.458	38.01	8.81	3.491	77.124	2
23.50	4.445	66.67	11.62	5.417	84.229	mean

For demonstration of the normalized parameters
and the formed mean values the results are plotted
in Annex A–7 ÷ A–9

**6.1.3.3.4 GAF – F–4F Simulation High g turn
Maneuver Comparison**

Parameter Comparison of Normalized Mean Values

Maneuver Time (sec)	Normal Load Factor n_z (–)	Roll Rate (deg/sec)	Pitch Rate (deg/sec)	Yaw Rate (deg/sec)	Δ Bank Angle (deg)	Maneuver Identification Number
19.76	5.479	66.63	14.622	5.123	86.485	1
19.16	5.051	92.19	19.657	10.556	86.334	2
16.12	5.100	81.07	24.508	6.491	92.159	3
23.20	6.710	105.83	30.239	9.809	91.562	4
19.56	5.585	86.43	22.257	8.00	89.135	mean

Recorded extreme values of single maneuver parameters and formed mean values

For demonstration of the normalized parameters
and the formed mean values the results are plotted
in Annex A–10 ÷ A–12

6.1.3.3.5 GAF – JF–90 Simulation High g turn
Maneuver Comparison

Parameter Comparison of Normalized Mean Values

Legend

o = nz Load Factor
▲ = Roll Rate
+ = Pitch Rate
× = Yaw   Rate
◇ = Bank Angle

Maneuver Time (sec)	Normal Load Factor n_z (–)	Roll Rate (deg/sec)	Pitch Rate (deg/sec)	Yaw Rate (deg/sec)	Δ Bank Angle (deg)	Maneuver Identification Number
12.16	8.858	75.943	19.477	6.551	90.924	1
9.84	8.189	101.666	21.480	16.247	87.362	2
18.68	7.865	50.883	24.373	16.094	85.339	3
16.26	8.085	184.489	18.424	24.423	91.750	4
15.72	7.197	147.188	18.583	24.886	87.010	5
14.53	8.039	112.038	20.467	17.640	88.477	mean

Recorded extreme values of single maneuver parameters and formed mean values

For demonstration of the normalized parameters
and the formed mean values the results are plotted
in Annex A–13 ÷ A–15

6.1.4 USAF – Aircraft – Data

6.1.4.1 Recording System

The F–16 is a Multi–role fighter used in both air–to–air and air–to–ground scenarios. It is unique in the sense that it is a totally "fly–by–wire" system. The pilot commands the aircraft by applying varying force levels on the control stick. Both the magnitude and direction of this force, are relayed to the flight control computer, which, in turn commands movement of the control surfaces in order to best accommodate the pilots request without causing a departure and subsequent loss of aircraft and possibly pilot. Another feature of the F–16C is that it is equipped with a flight loads recorder that stores time histories of 17 airframe and 10 engine parameters from the point in time when power is applied to the aircraft until the airplane is powered down.

The recorder that provides this information is called a Crash Survivable Flight Data Recorder (CSFDR) and has three functions. The first is to survive in the event of a mishap to save the information for investigative purposes. It also is used for individual aircraft tracking (lAT) for the purpose of monitoring airframe usage and as a general flight loads recorder to store information concerning the loading and various flight conditions that are seen during operation.

The CSFDR records 15 parameters, as listed in Figure 6.5 that are associated with the airframe and flight conditions of attack, roll, pitch and yaw rates and accelerations, left and right flaperon and horizontal tail. Each signal has a lower and upper threshold that determines when a recording should take place. Complete time hack of data is recorded at peaks and valleys of any of eight structurally significant parameters, and when the rate of change of any of a number of engine significant parameters is incremented by more than a specified amount. Consequently, when the CSFDR is downloaded from the aircraft a complete time history of these parameters is produced for each mission stored in the recorder.

CSFDR–Parameter

- Mach Number

- Altitude (ft)

- Longitudinal acceleration (n_x)

- Lateral acceleration (n_y)

- Normal acceleration (n_z)

- True angle of attack (deg)

- Roll rate (rad/ sec)

CSFDR–Parameter cont" d

- Roll acceleration (rad/ sec/ sec)

- Pitch rate (rad/ sec)

- Pitch acceleration (rad/ sec/ sec)

- Yaw rate (rad/ sec)

- Yaw acceleration (rad/ sec/ sec)

- Left / right flaperon deflection (deg)

- Left / right horizontal tail deflection (deg)

- Rudder deflection (deg)

Figure 6.5 CSFDR parameters overall list

6.1.4.2 Purpose of Recordings

The thrust behind this USAF activity was to determine whether or not it is possible to create a load case on an aircraft, the F–16 specifically, with a flight control system that exceeds those used for the initial design criteria. Will the pilot's maneuvers change due to this type of system? Will the flight control system itself produce higher loads in fulfilling the pilot's request? Also, is the high thrust–to–weight ratio associated with the F–16 capable of producing these higher loads?

The information–contained in this presentation is a sampling of information that was acquired during the Sep 88 to Dec 88 time frame. John Slye was a member of a joint Air Force / General Electric team who traveled to four operational F–16 bases operating F–16 C/D versions with functional CSFDR's. This team spent approximately two weeks at each facility processing CSFDR data and interviewing pilots in order to better understand how the aircraft was being flown during air–to–air and air–to–ground missions. Over 300 sorties from 97 different aircraft were analyzed. Those used for this presentation are air–to–air type missions only, specifically, basic fighter maneuvers (BFM) and air combat maneuvers (ACM). These two types produce higher loading conditions on the aircraft than other air–to–air or air–to– ground missions because they are the traditional "dogfight" kinds of sorties. A presentation on the findings of the survey on engine usage was given at the 68th meeting of the AGARD / SMP in Ottawa, Ontario, Canada by Captain Timothy Fowler.

The data provided for the WG 27 study was a selected subset of the F–16 fleet monitoring data.

6.1.4.3 USAF – Normalized Time Histories

6.1.4.3.1 USAF – F–16 High g turn
Maneuver Comparison

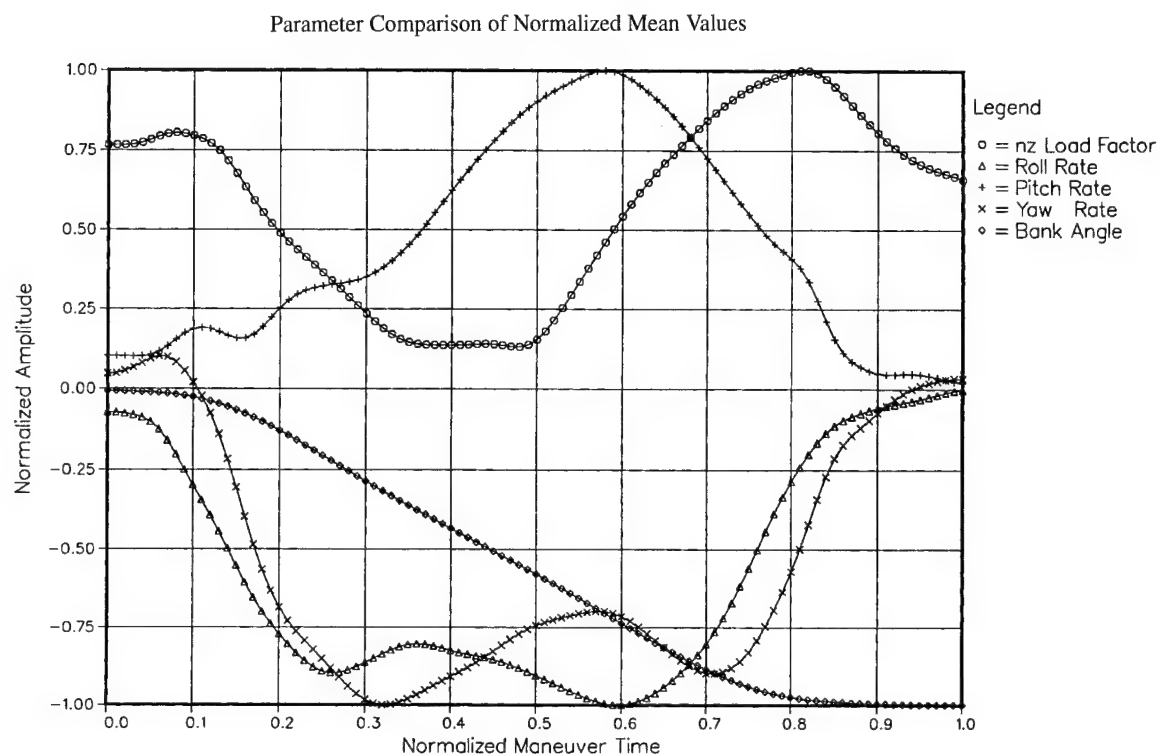Parameter Comparison of Normalized Mean Values

Maneuver Time (sec)	Normal Load Factor n_z (–)	Roll Rate (deg/sec)	Pitch Rate (deg/sec)	Yaw Rate (deg/sec)	Δ Bank Angle (deg)	Maneuver Identification Number
6.20	4.622	112.33	20.597	16.240	93.165	1
8.00	4.074	80.23	12.785	8.021	85.424	2
14.40	5.074	70.03	11.959	8.246	86.727	3
10.80	6.424	63.18	17.189	6.262	93.251	4
11.00	4.422	55.11	10.863	2.865	88.017	5
18.20	6.952	47.88	18.335	6.303	95.376	6
8.80	2.793	76.69	14.007	7.813	78.435	7
10.30	5.680	112.46	16.329	11.373	86.133	8
9.90	7.040	70.03	18.225	13.178	75.608	9
10.40	4.238	54.35	9.167	2.865	95.206	10
10.80	5.132	74.23	14.946	8.317	87.734	mean

Recorded extreme values of single maneuver parameters and formed mean values

For demonstration of the normalized parameters
and the formed mean values the results are plotted
in Annex A–16 ÷ A–18

6.1.4.3.2 USAF – F–16 Barrel roll
Maneuver Comparison

Parameter Comparison of Normalized Mean Values

Maneuver Time (sec)	Normal Load Factor n_z (–)	Roll Rate (deg/sec)	Pitch Rate (deg/sec)	Yaw Rate (deg/sec)	Δ Bank Angle (deg)	Maneuver Identification Number
6.00	2.410	96.83	15.470	16.043	471.175	1
7.40	2.619	114.59	12.174	9.061	407.827	2
7.20	1.798	76.78	11.850	10.871	386.781	3
6.86	2.276	96.07	13.165	11.990	421.918	mean

Recorded extreme values of single maneuver parameters and formed mean values

For demonstration of the normalized parameters
and the formed mean values the results are plotted
in Annex A–19 ÷ A–21

6.1.5 CF–Aircraft–Data

6.1.5.1 CF–18 Maintenance Signal Data Recording System

The MSDRS was developed by MCAir to provide fatigue usage, flight incident records, engine usage data and associated maintenance data. The system is used on the AV–8B and EA–6B, as well as the CF–18. Components of the system comprise an on–board processor and a data recorder that writes to a magnetic tape cartridge. A ground station is used to strip the data from the cartridges and make it available for engineering use.

Various parameters are grouped together in MSDRS messages and identified by record codes. These messages are recorded when triggered by an exceedence of a threshold on selected channels. The fatigue Code 49 is triggered when the normal acceleration reaches a peak or valley.
Other codes are triggered by engine events or weapons release. (Note that several messages may be triggered by the same event such as a landing. If this happens, there is a hierarchy for defining the recording sequence. Data can be lost if the number of messages stacked exceeds the buffer size). The flight incident record (Code 46) is written every second, whilst the continuity message (Code 120) that contains the state of the weight–on–wheels switch, is recorded every five minutes and at take–off and landing. A list of codes that are pertinent to the CF–18 fatigue load spectrum development is given in Table 1. All recorded data are time related.

Record Code	Description
4	Fatigue Monitoring–Weapons inventory
21	Recorder Initialization
22	Recorder Summary Message @
31	Engine Data Life Cycles
46	Flight Incident Records
48	Fatigue Monitoring Initialization
49 to 62	Fatigue Sensor Peaks and Valleys
65	Configuration Message
120	Continuity Data

Table 1: MSDRS codes used for usage processing and maneuver identification.

The MSDRD records used for usage processing are Codes 4, 46, 47 and 49 to 62. The parameters of interest are given in Tables 2, 3 and 4.

6.1.5.1 CF–18 Maintenance Signal Data Recording System

Parameter	Recording Frequency (H_z)
IAS	1
Pressure altitude	1
Roll rate	1
Angle of attack	1
Longitudinal stick position	1
Lateral stick position	1
Rudder pedal position	1
Normal acceleration	1
Fuel quantity	0.2
Control surface positions	0.2

Table 2: Flight Incident Parameter List

Parameter

Normal acceleration *
Forward fuselage strain *
Wing root strain *
Left stabilator strain *
Right stabilator strain *
Left fin root strain*
Right fin root strain*
Fuel quantity
TAS
Altitude
Roll rate

* Fatigue Sensor Triggered Parameters recorded on every peak valley of these parameters

Table 3: Fatigue Sensor Triggered Parameter List.

Max n_z *
Aircraft weight W
Max. vertical velocity *
First weight–on–wheels
Max $n_z \cdot W$ *

*) These parameters are the maximum values in the 2.05 seconds before weight–on–wheels

Table 4: Landing Parameter List.

6.1.5.2 Purpose of Recording

Early in 1986, analysis of fleet usage indicated that the CF–18 aircraft were being operated in a significantly different manner that assumed for design, and that the severity of the usage approached and in some cases exceeded the spectrum used for certification testing. Furthermore as the manufacture's certification testing progressed and failures were encountered, configuration changes were introduced on the production lines or proposed as fleets retrofit to improve the fatigue characteristics of deficient components. A large number of these improvements to fracture critical elements were certified based on analysis or limited coupon testing only and were never subjected to full scale testing to a representative CF spectrum. As a result of these uncertainties the CF is currently applying a scatter factor of three to the manufacturer's full scale result. The reduction in certified life and increased usage severity have raised concerns regarding the potential for the CF–18 to reach its required life expectancy and to provide any possibility for life extension.

In order to resolve this fleet management problem, the CF implemented an aggressive Fatigue Life Management Program (FLMP) to minimize fatigue damage accrual and decided in 1989 to proceed with a follow–on full scale test of the CF–18 airframe to establish its safe life under a representative spectrum. The CF–18 full scale test is being conducted as a collaborative effort between Canada and Australia who share the same structural integrity concerns regarding the reduced structural life. This joint program is usually referred to as the International Follow–On Structural Test Project (IFOSTP). Within the program Canada will be responsible for testing the centre fuselage and empennage. The requirement to realistically simulate the empennage buffet loads environment lead to this division of responsibilities.

In Canada the centre fuselage test and balanced load derivation is carried out by Canadair, Defence Systems Division while the development of the test spectra and wing test is under the responsibility of the Institute for Aerospace Research/Structures and Materials Laboratory. To yield an accurate fatigue test result, the derivation of the external balanced loads and the calculation of the aircraft component loads were crucial undertakings of IFOSTP.

The design spectrum for the F/A 18 was based upon 3 points in the sky (PITS). The Canadian usage spectrum differs significantly from the original design spectrum. It was established from the maintenance signal data recording system (MSDRS).

The MSDRS provides a mean to get manoeuvre usage data since it records most of the essential flight parameters to define a maneuver. It also records strain data for any normal load factor (n_z) or roll acceleration excursion.

Strain sensors, located at the wing root, wing fold, forward fuselage, horizontal stabilator and vertical stabilizer allow fatigue life prediction at these locations.

Using this system, a 300 hours block sample was extracted. This data represents 4 different aircraft and 270 flights. Over 12,000 different maneuvers formed the usage block mentioned above. The MSDRS system recorded over 70,000 turning points with

potential fatigue significance. This constitutes the maneuver spectrum used for the IFOSTP Centre Fuselage Test.

Loads were derived for every point called MSDRS trigger or trigger point. Since the test is done on a complete aircraft, the loads have to be brought to a dynamic equilibrium between aerodynamic and inertia loads. This is called loads balancing.

The loads were validated with flight test results. For this purpose, four extremely severe maneuvers were selected from an IFOSTP flight test program performed by the Australian team, more specifically by Aeronautical Research and Development Unit, a division of the Royal Australian Air Force (RAAF) and the Aeronautical and Maritime Research Lab in Melbourne.

The MSDRS recording system is mounted on all Canadian Forces CF–18 aircraft and is used to individually track the usage of each aircraft. These data are used as a major input to the life cycle management of the CF–18 fleet. The data provided for the WG.27 study was a subset of the CF–18 fleet monitoring data that is being used to formulate a test spectrum for a full scale test of the CF–18 wing and center fuselage structures.
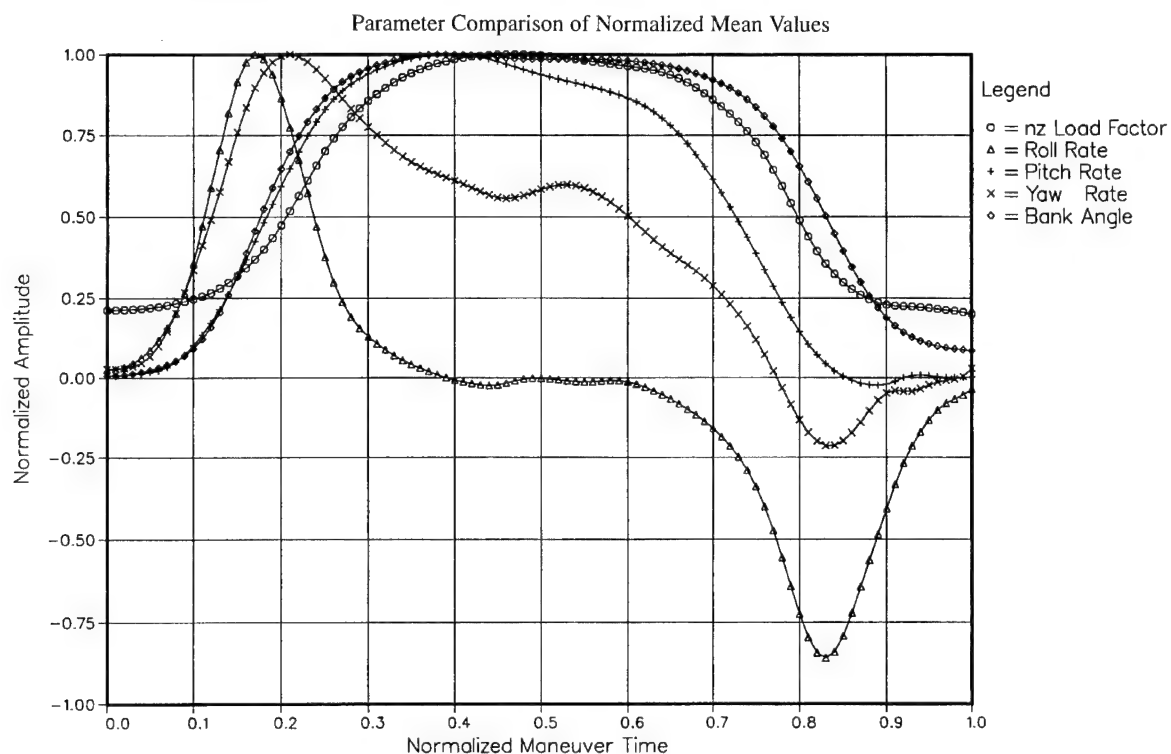
30

6.1.5.3 CF – Normalized Time Histories
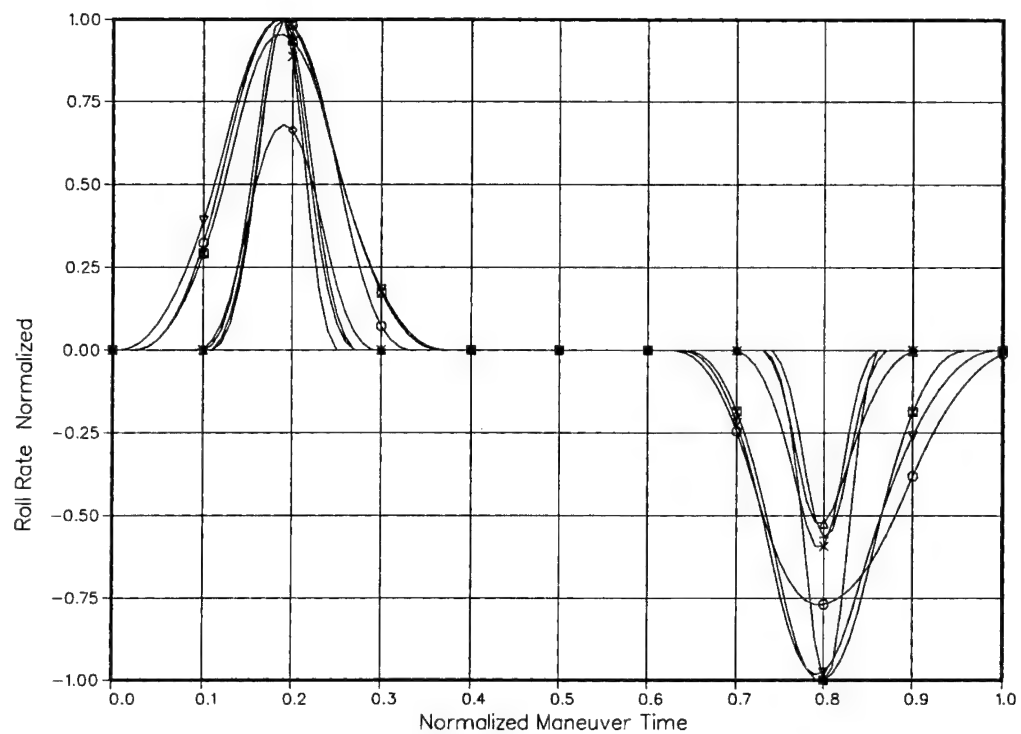
6.1.5.3.1 CF – CF–18 High g turn

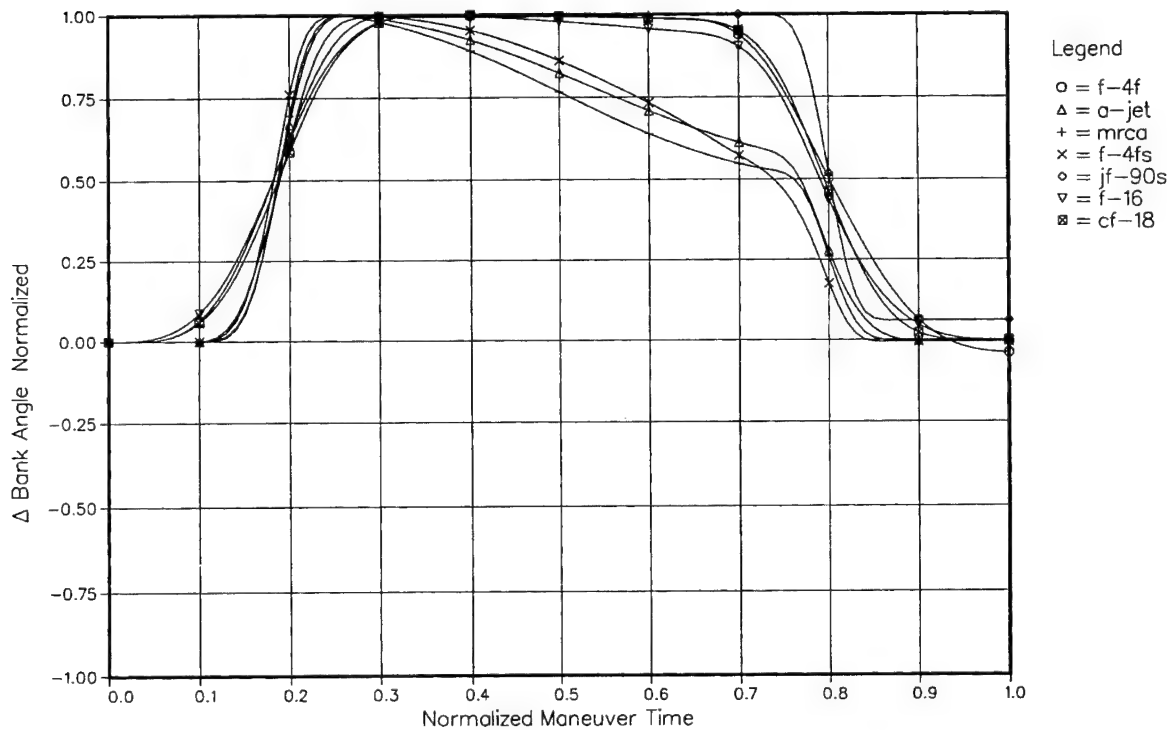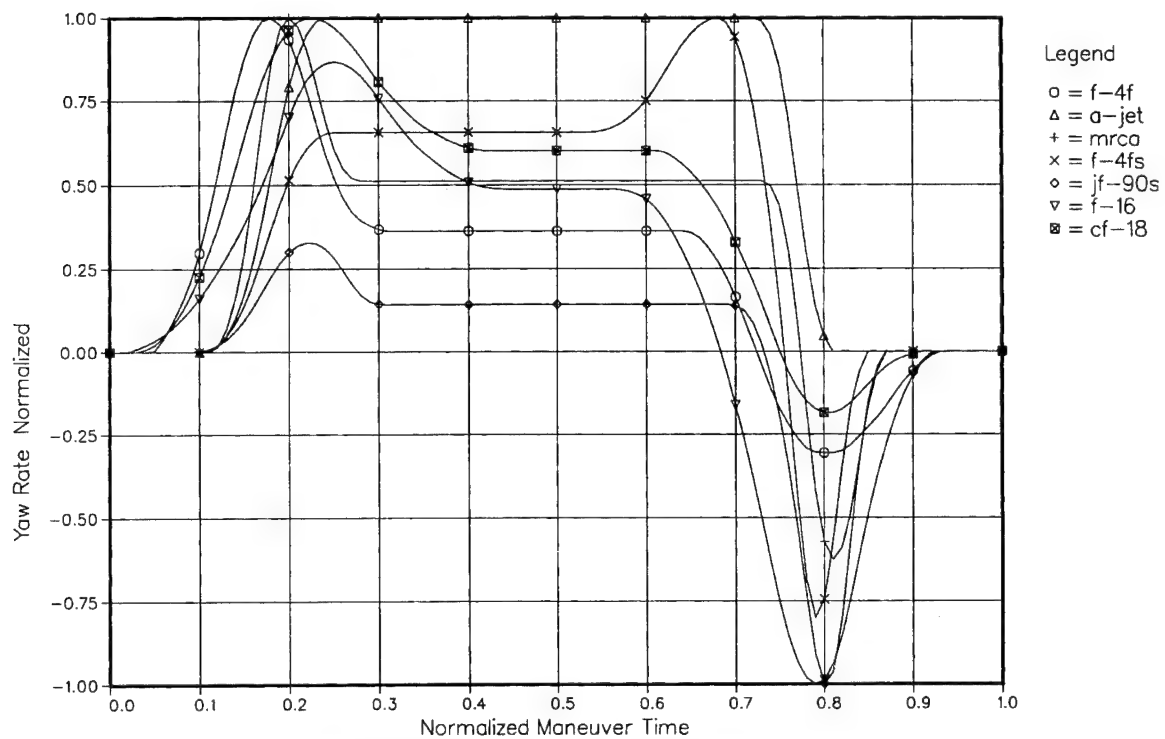Parameter Comparison of Normalized Mean Values

| Maneuver Time (sec)	Normal Load Factor n_z (–)	Roll Rate (deg/sec)	Pitch Rate (deg/sec)	Yaw Rate (deg/sec)	Δ Bank Angle (deg)	Maneuver Identification Number
9.90	4.591	84.93	10.601	6.810	88,600	m00256
6.60	5.216	73.78	13.487	6.493	92.542	m00442
8.60	4.470	37.67	9.921	3.500	78.001	m02006
10.10	6.057	76.68	13.000	6.492	86.224	m02043
11.90	5.331	55.16	12.545	3.498	77.005	m02539
9.00	4.096	61.39	9.030	3.550	81.566	m02712
6.90	5.727	51.99	14.118	7.497	85.818	m03199
10.70	5.227	53.91	10.678	2.501	80.559	m05799
13.50	4.712	71.32	12.762	4.501	79.072	m06450
17.60	5.934	63.09	13.585	4.012	83.770	m06558
11.00	5.067	41.43	11.494	4.510	84.414	m08693
8.90	5.905	89.16	10.866	3.697	88.201	m09117
10.80	5.370	97.92	10.584	3.508	87.612	m09317
11.10	4.858	45.46	9.828	2.473	75.891	m09598
10.57	5.190	64.58	11.607	4.500	83.71	mean

Recorded extreme values of single maneuver parameters and formed mean values

For demonstration of the normalized parameters
and the formed mean values the results are plotted
in Annex A–22 ÷ A–24

### 6.1.5.3.2 CF – CF–18 Barrel roll

Parameter Comparison of Normalized Mean Values

Maneuver Time (sec)	Normal Load Factor n_z (–)	Roll Rate (deg/sec)	Pitch Rate (deg/sec)	Yaw Rate (deg/sec)	Δ Bank Angle (deg)	Maneuver Identification Number
6.550	1.740	119.71	5.458	7.633	369.114	m00943
6.850	1.740	131.97	3.494	9.493	357.331	m03135
5.850	1.620	139.62	4.489	8.495	355.066	m05523
6.850	1.526	123.00	4.581	6.496	366.296	m07533
7.450	0.373	91.79	1.849	5.583	360.212	m08863
3.850	2.240	144.85	5.499	6.512	379.510	m10633
4.150	2.360	144.97	7.500	15.502	393.596	m10676
5.936	1.657	127.99	4.696	8.531	368.732	mean

Recorded extreme values of single maneuver parameters and formed mean values

For demonstration of the normalized parameters
and the formed mean values the results are plotted
in Annex A–25 ÷ A–27

6.2 Aircraft – Comparison of Normalized Time Histories

6.2.1 Aircraft Comparison
High g turn – mean value
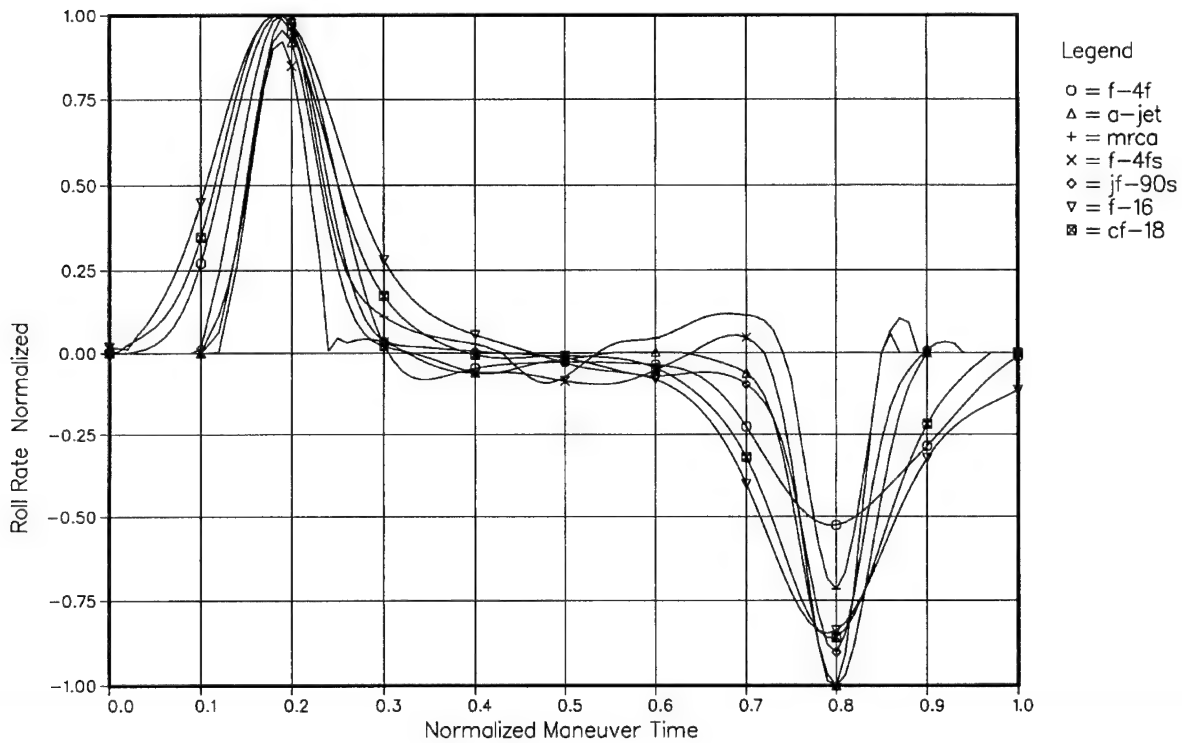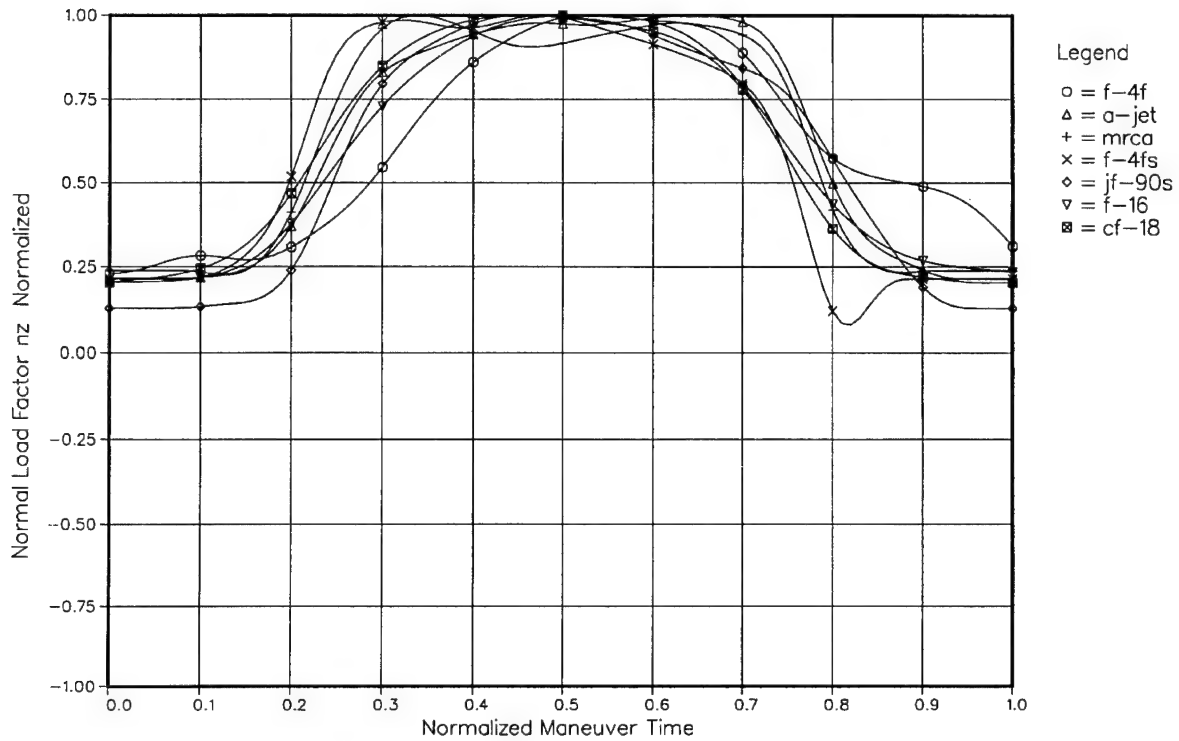
Legend

o = f−4f
△ = a−jet
+ = mrca
× = f−4fs
◇ = jf−90s
▽ = f−16
▣ = cf−18

Legend

o = f−4f
△ = a−jet
+ = mrca
× = f−4fs
◇ = jf−90s
▽ = f−16
▣ = cf−18

6.2.1 Aircraft Comparison
High g turn–mean values

Legend

o = f−4f
Δ = a−jet
+ = mrca
× = f−4fs
◇ = jf−90s
▽ = f−16
⊠ = cf−18

Pitch Rate Normalized vs *Normalized Maneuver Time*

Legend

o = f−4f
Δ = a−jet
+ = mrca
× = f−4fs
◇ = jf−90s
▽ = f−16
⊠ = cf−18

Yaw Rate Normalized vs *Normalized Maneuver Time*

6.2.1   Aircraft Comparison
      High g turn–mean values

Comparison of mean maneuver parameters for different aircraft
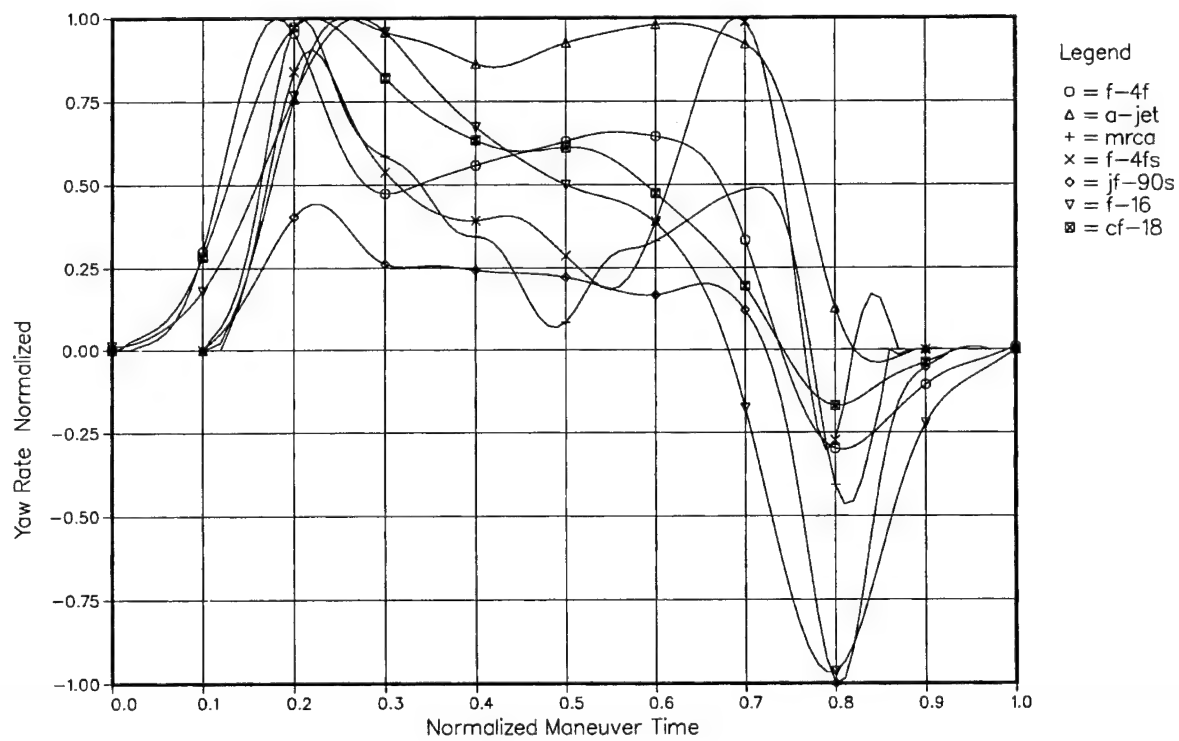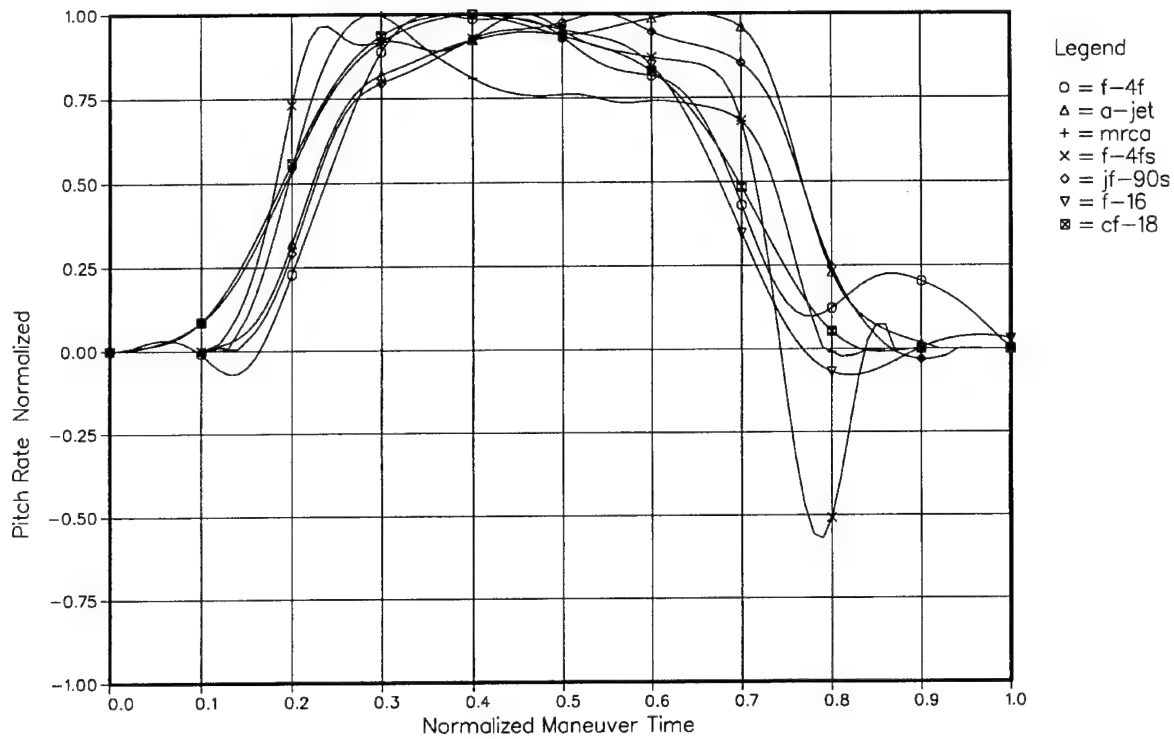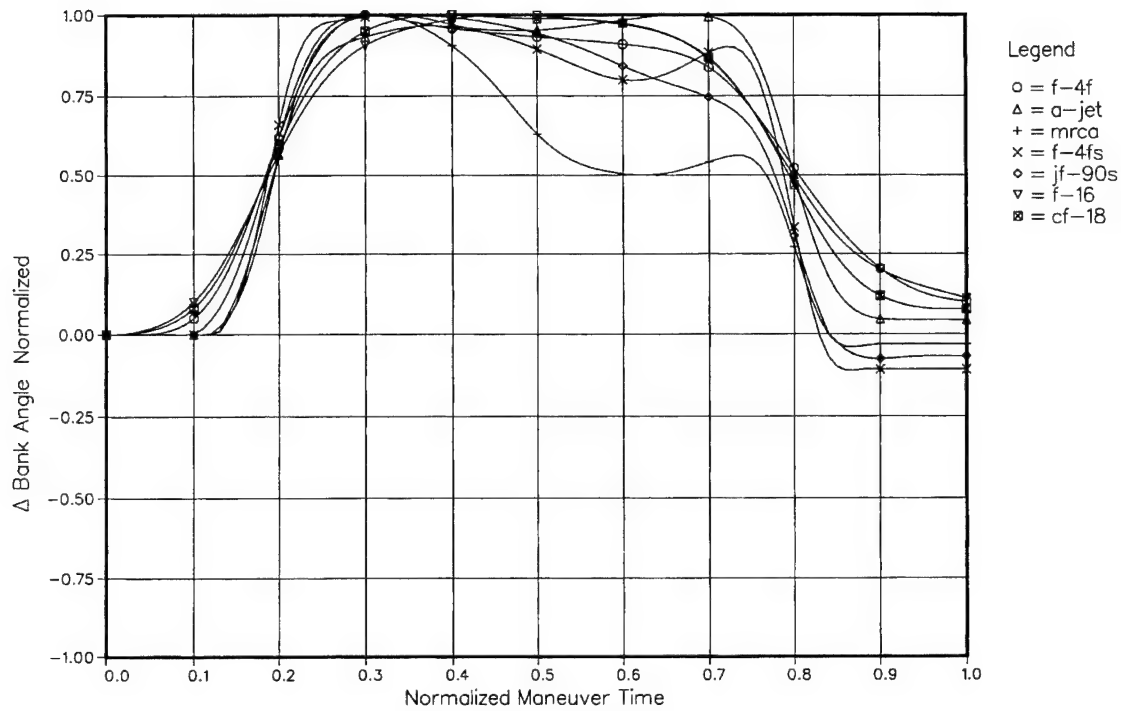
Maneuver Time (sec)	Normal Load Factor n_z (–)	Roll Rate (deg/sec)	Pitch Rate (deg/sec)	Yaw Rate (deg/sec)	Δ Bank Angle (deg)	Maneuver Identification Number
8.11	4.610	99.67	14.164	4.515	85.436	F–4F
23.50	4.743	68.79	11.939	3.210	84.264	A–JET
23.50	4.445	66.67	11.620	5.417	84.229	MRCA
19.56	5.585	86.43	22.257	8.000	89.135	F–4Fs
14.53	8.039	112.04	20.467	17.640	88.477	JF–90
10.80	5.132	74.23	14.946	8.317	87.734	F–16
10.57	5.190	64.58	11.607	4.500	83.710	CF–18

6.2.2 High g turn Standardized Values

6.2.2 High g turn Standardized Values

6.2.3 Barrel roll mean values

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6.2.3 Barrel roll mean values

Legend
o = f−4f
Δ = a−jet
+ = f−16
× = cf−18

Legend
o = f−4f
Δ = a−jet
+ = f−16
× = cf−18
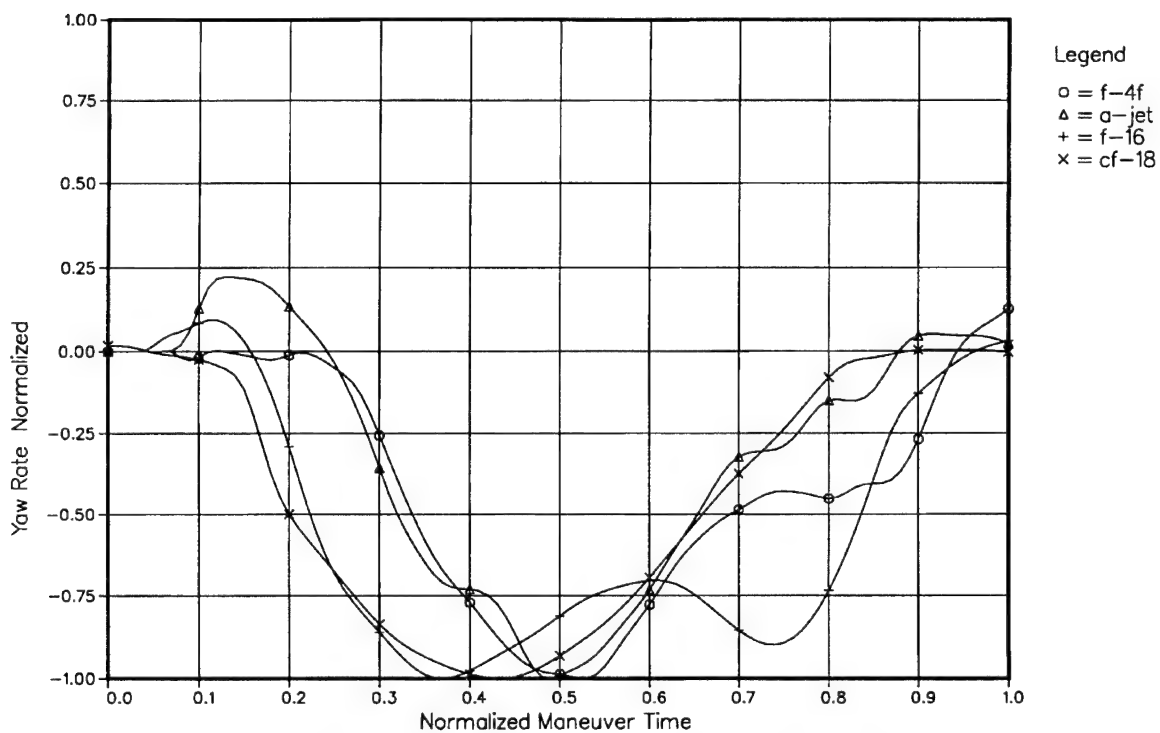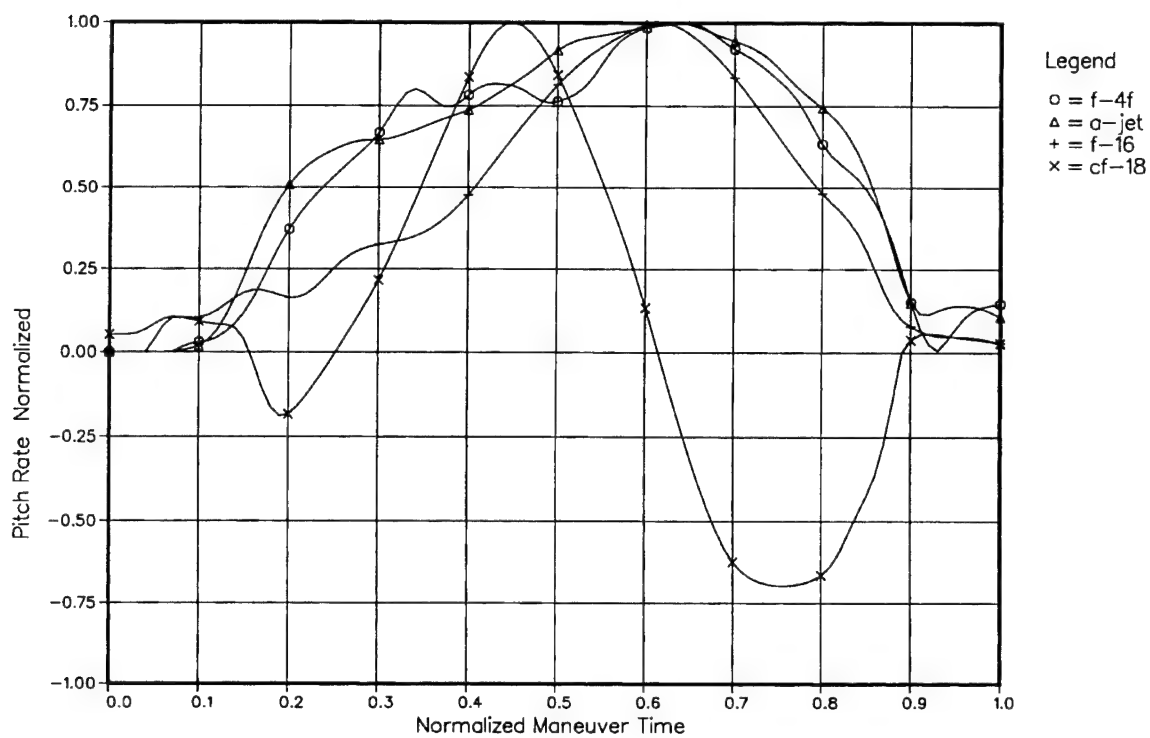
6.2.3 Barrel roll mean values

Maneuver Time (sec)	Normal Load Factor n_z (–)	Roll Rate (deg/sec)	Pitch Rate (deg/sec)	Yaw Rate (deg/sec)	Δ Bank Angle (deg)	Maneuver Identification Number
23.91	4.47	36.41	14.12	5.90	363.00	F–4F
29.33	6.02	26.60	15.19	4.14	364.00	A–JET
7.07	1,26	96.10	13.17	12.00	362.00	F–16
5.98	1.83	127.99	4.70	8.53	369.00	CF–18

Comparison of mean maneuver parameters for different aircraft

6.2.4 Barrel roll Standardized Values
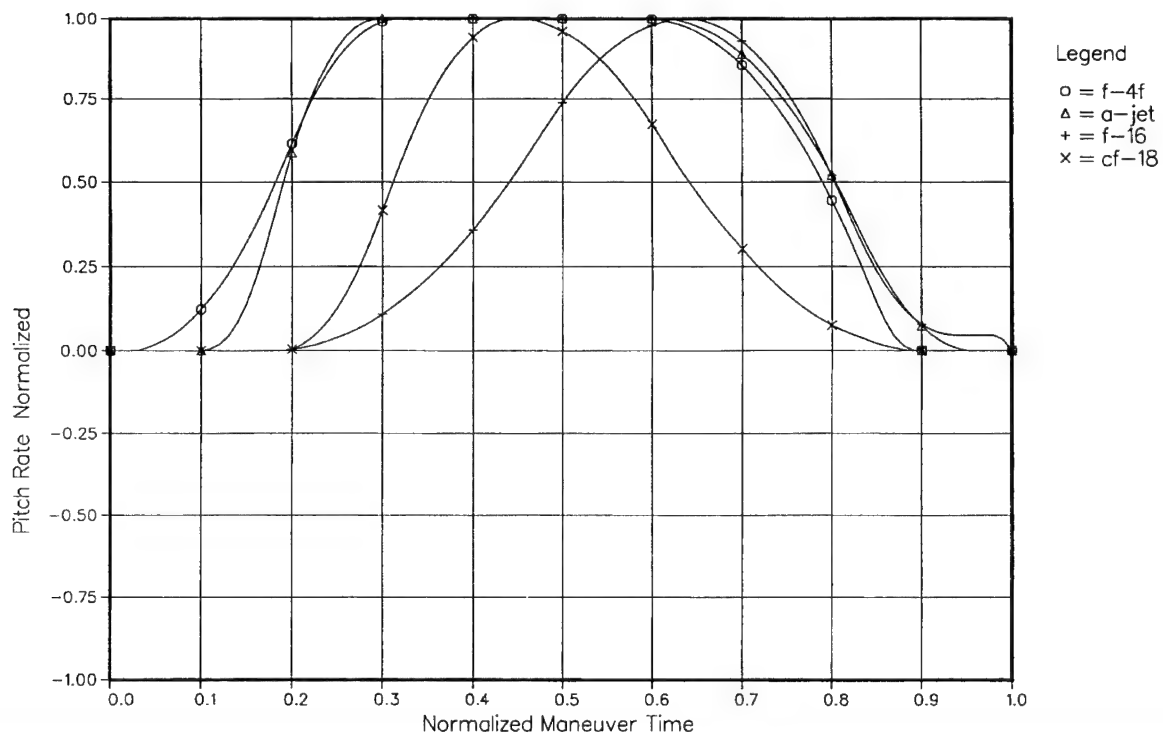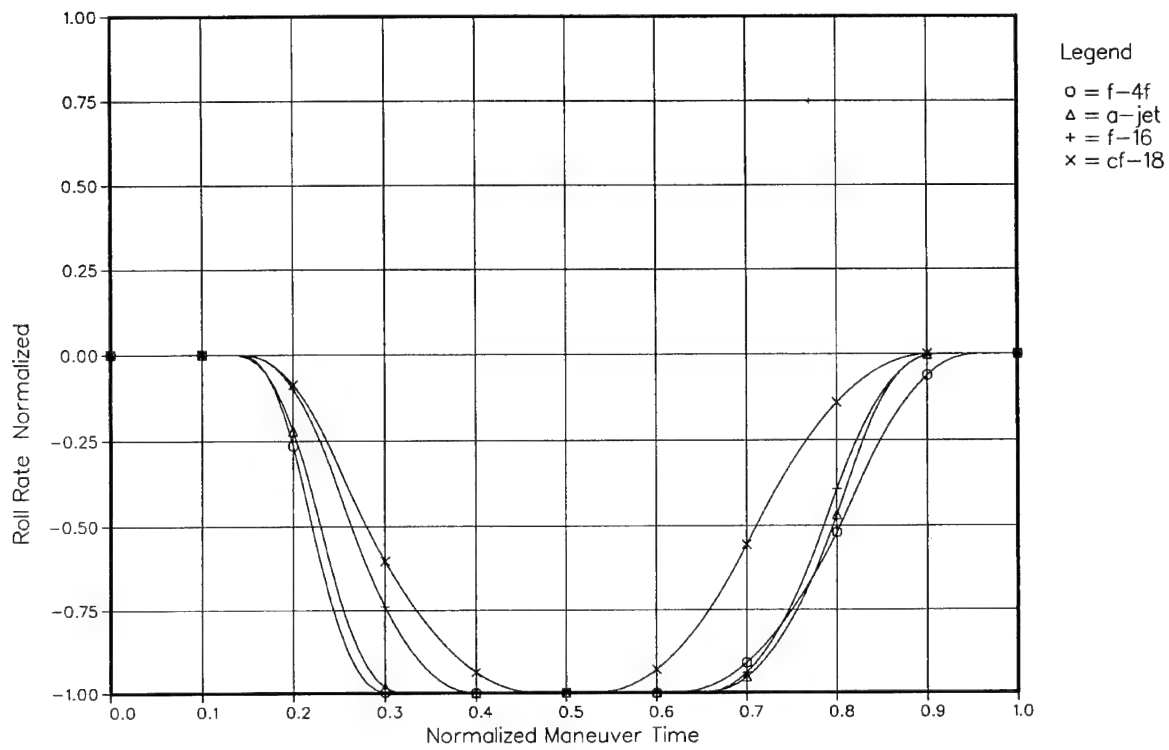
6.2.4   Barrel roll Standardized Values
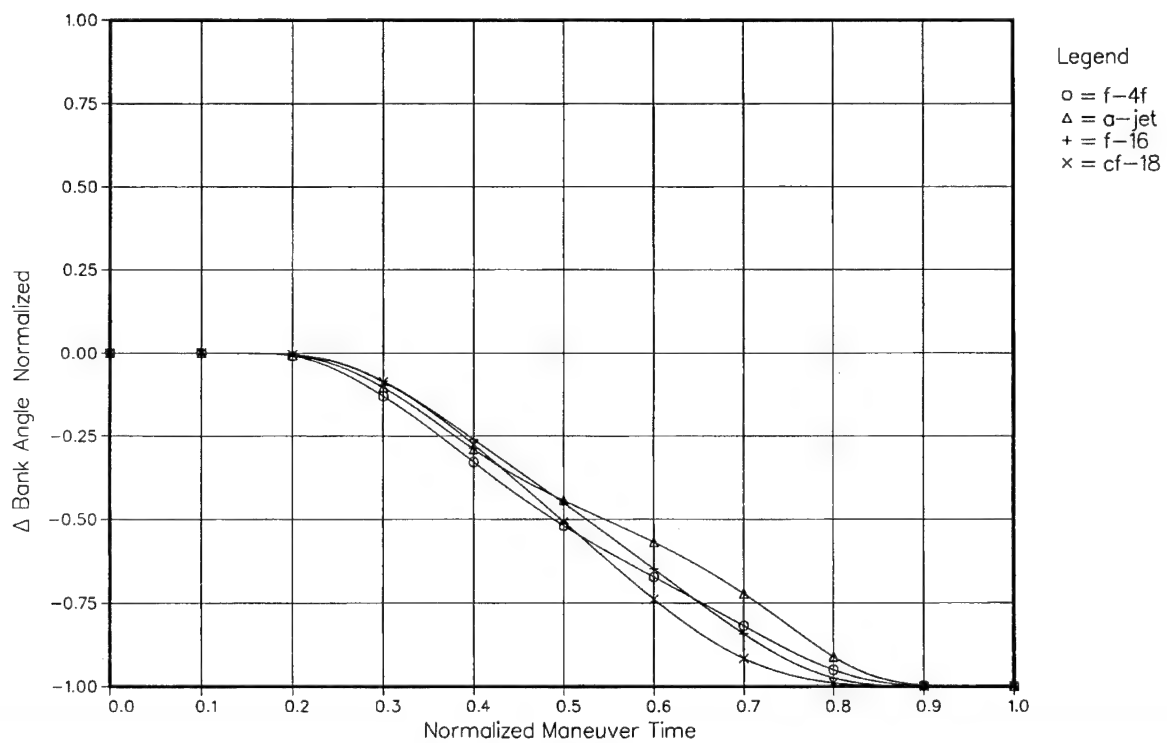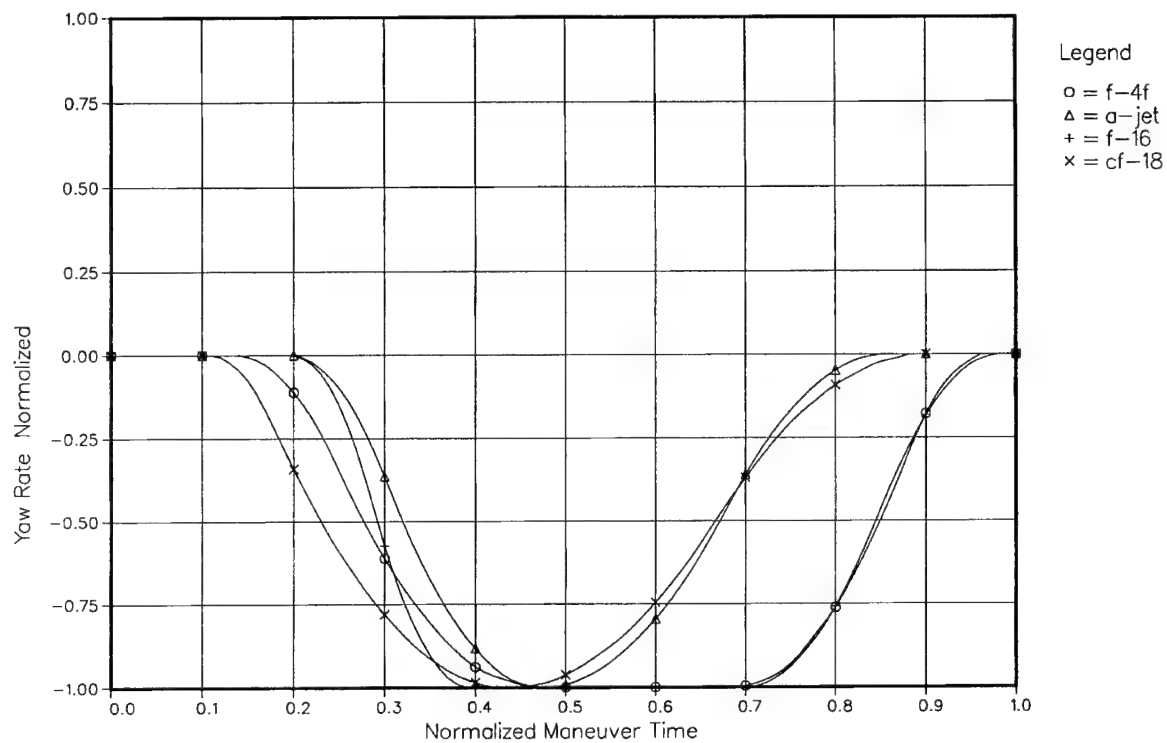
6.3 WG.27 Maneuver Time Histories Reconstitution

6.3.1 Reconstitution Process

The Flow chart in Figure 6.3 presents the general data flow and indicates the major phases of the WG.27 approach.
For the application of the WG.27 procedure (chapter 6.0), a re-constitution of the standard maneuver into real time is necessary for any calculation of loads.
For the reconstitution, the following is required:

- The Boundary conditions (chapter 5.4) of the se-lected maneuver type. In this case the boundary conditions are the maximum values of:

  - Load factors n_x, n_y, n_z
  - Roll rate
  - Pitch rate
  - Yaw rate
      and

  - Maneuver time (whole maneuver time)

- The standard maneuver time histories of the se-lected maneuver type.

  - load factors, n_x, n_y, n_z
  - roll rate
  - pitch rate
  - yaw rate

The maximum values of the "boundary conditions" including maneuver time are the reconstitution factors.

The reconstitution into real time is given by:

$$y = Y * \text{reconstitution factor}$$

$$\dot{y} = y_{dot} = \frac{\Delta y}{\Delta x}$$

$y = f(t) \quad t_{man} = T * \text{maneuver time} \quad Y = \text{normalized amplitude}$

$y = f(t) \quad \Delta x = \frac{t_{man}}{100} \qquad T = \text{normalized time}$

Figure 6.3 WG.27 Approach

Recorded Operational Parameters F–16 / CF18 — 5.2

Maneuver – Identification 5.2 F–16/CF18

CF–18 / F–16

Boundary Conditions for Maneuver Type man_02043, man_02712, man_05799 — 5.4 — A B

Operational Parameters Time Histories for Standard Maneuver Type — 5.3 — A B

CF–18 Aircraft Basic Data — 5.5

Reconstitution Process — 6.3

WG–27 MANEUVER MODEL (Canadian Loads Process) — 6.4

Major Section loads (Reconstituted) for CF–18 — A B

Major Section Loads from IFOSTP Test Program man_02043, man_02712,man_05799 — A B

Comparison of Major Section Loads Reconstituted / IFOSTP — 6.4 — A B

A= High g Turn
B= Barrel Roll

This chapter (6.3.1) contains the results of four reconstitutions that demonstrate the process and its accuracy.

The first maneuver is a standardized CF–18 high g turn maneuver reconstituted to real time using the reconstitution factors of a CF–18 high g turn maneuver with a minimum n_z–rate. man_02712

The second maneuver is the similar CF–18 standard maneuver reconstituted to real time using the reconstitution factors of a CF–18 high g turn maneuver with a maximum n_z–rate. man_05799

The third maneuver is a standardized F–16 high g turn maneuver reconstituted to real time using the reconstitution factors of a CF–18 high g turn maneuver with a high n_z–level. man_02043

The last maneuver is a standardized F–16 Barrel roll maneuver reconstituted to real time using the reconstitution factors of a CF–18 Barrel roll maneuver with a high roll rate. man_05523

For these 4 maneuvers the time histories have been plotted for comparison. The plots are showing the comparison of the reconstituted– and the real time histories of the selected maneuvers.

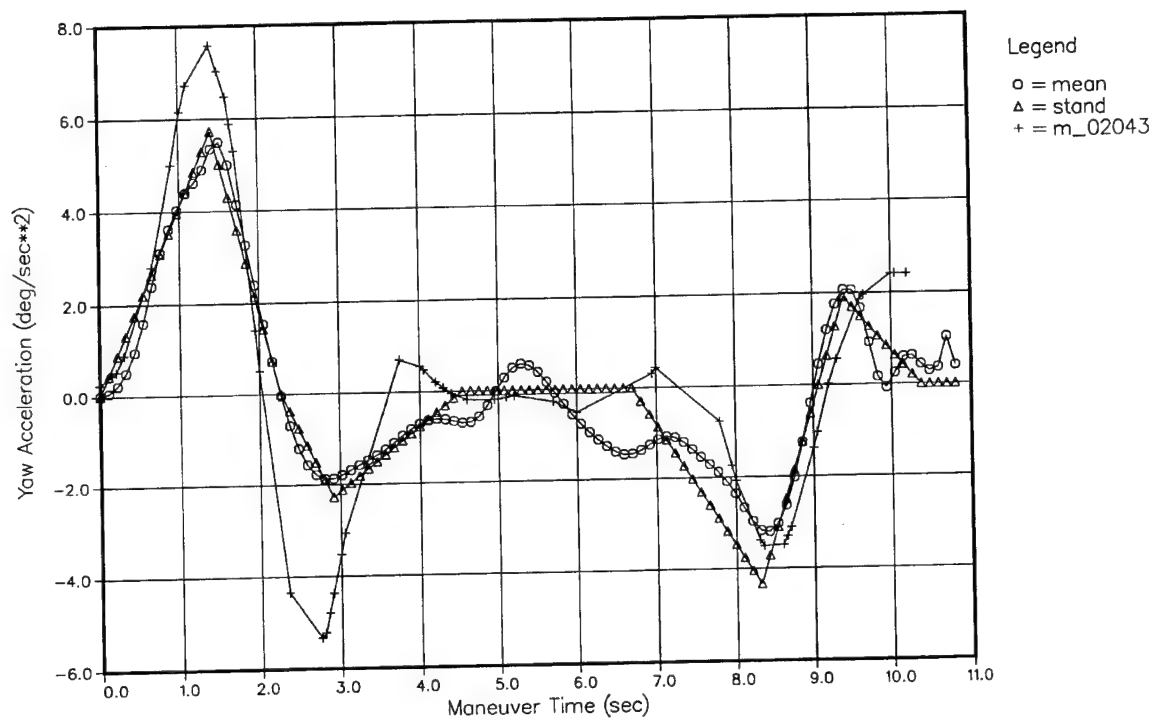**6.3.1.1 – CF–18 High g turn Mean Maneuver Reconstituted with CF–18–Maneuver Data (min n_z–rate)**

6.3.1.1 – CF–18 High g turn Mean Maneuver
Reconstituted with CF–18–Maneuver Data
(min n$_z$–rate)

Legende
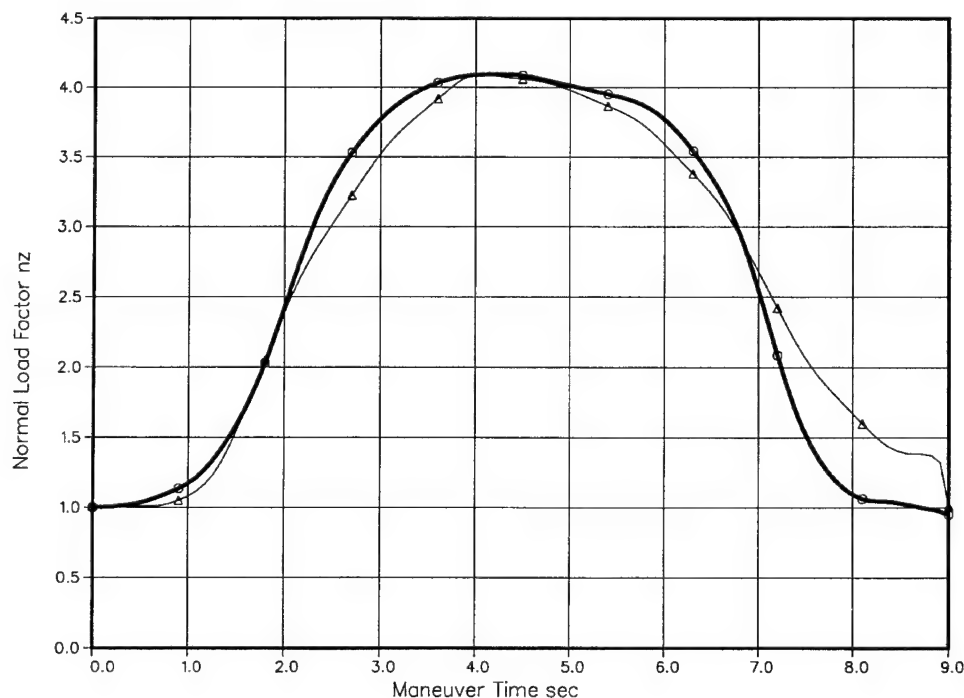
o = Recon.
Δ = m02712

Legende

o = Recon.
Δ = m02712

6.3.1.1 – CF–18 High g turn Mean Maneuver Reconstituted with CF–18–Maneuver Data (min n_z–rate)
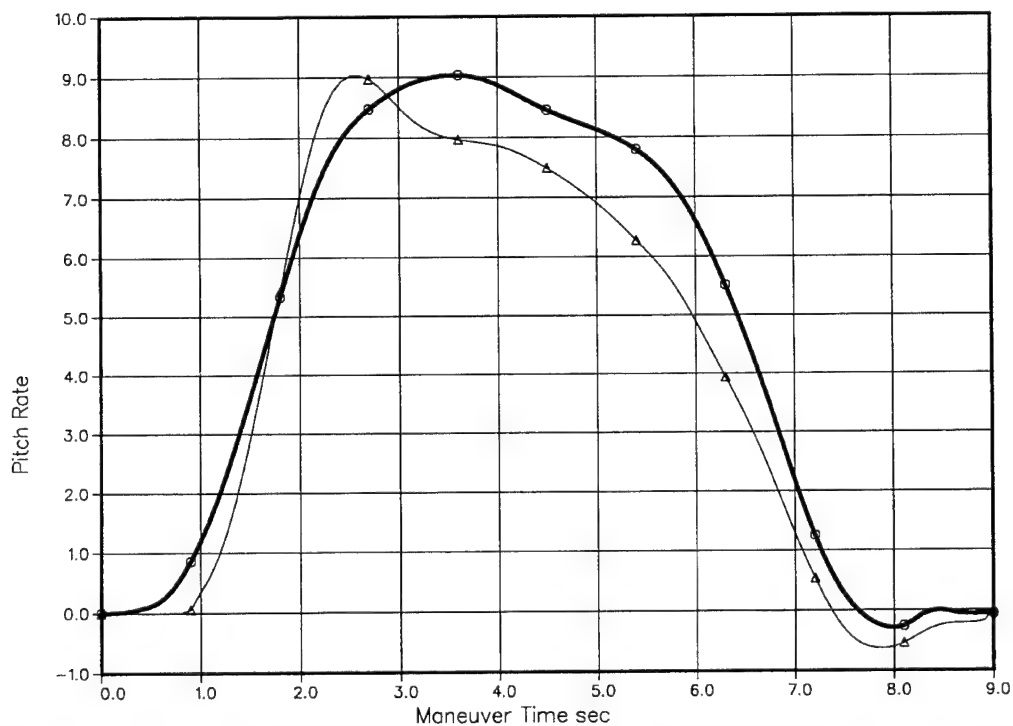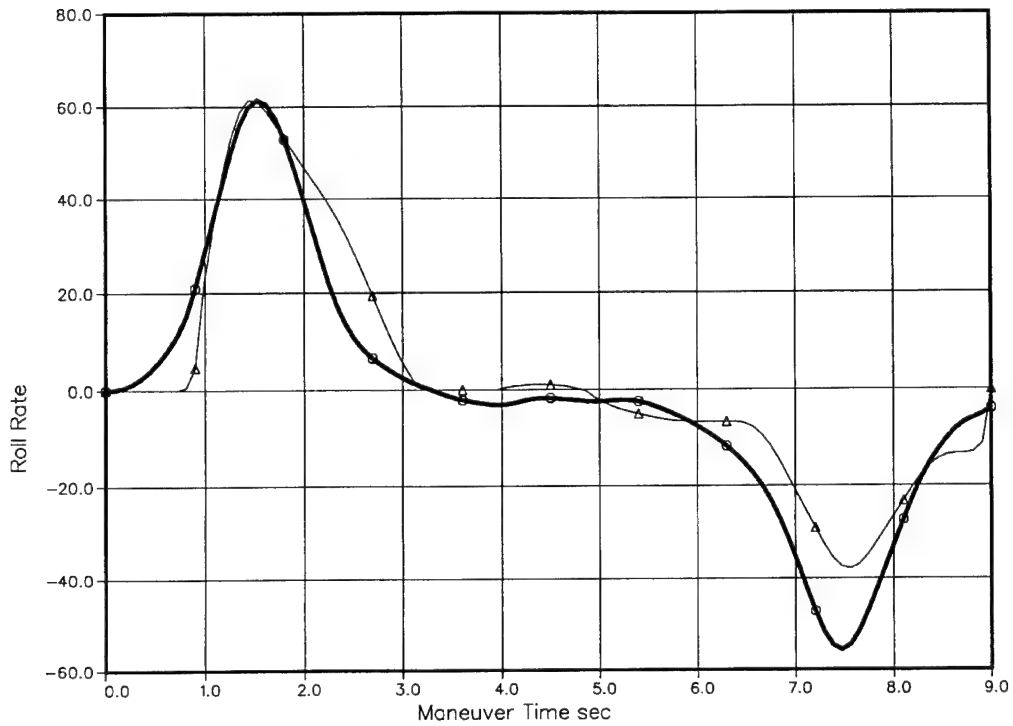
Legende

o = Recon.
Δ = m02712

Legende

o = Recon.
Δ = m02712

6.3.1.2 – CF–18 High g turn Mean Maneuver
Reconstituted with CF–18–Maneuver Data
(max n_z–rate)

Legende

o = Recon.
Δ = m05799

Legende

o = Recon.
Δ = m05799

6.3.1.2 – CF–18 High g turn Mean Maneuver
Reconstituted with CF–18–Maneuver Data
(max n_z–rate)

6.3.1.2 – CF–18 High g turn Mean Maneuver
Reconstituted with CF–18–Maneuver Data
(max n_z–rate)

Legende

o = Recon.
Δ = m05799

6.3.1.3 – CF–18 High g turn Standard Maneuver Reconstituted with CF–18–Maneuver Data (max n$_z$–level)
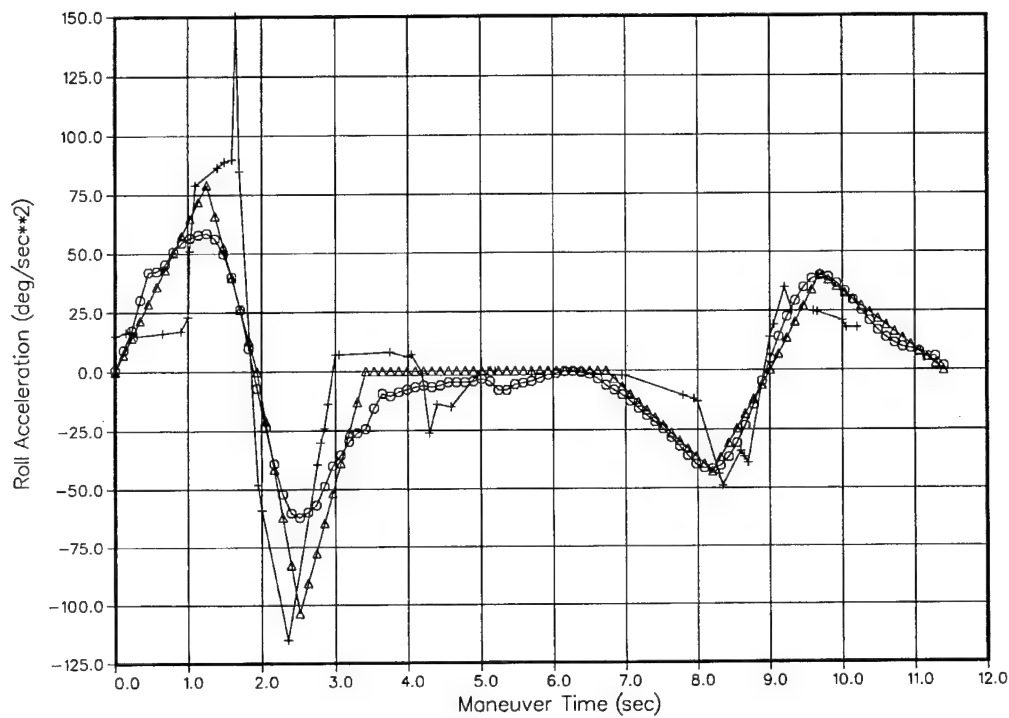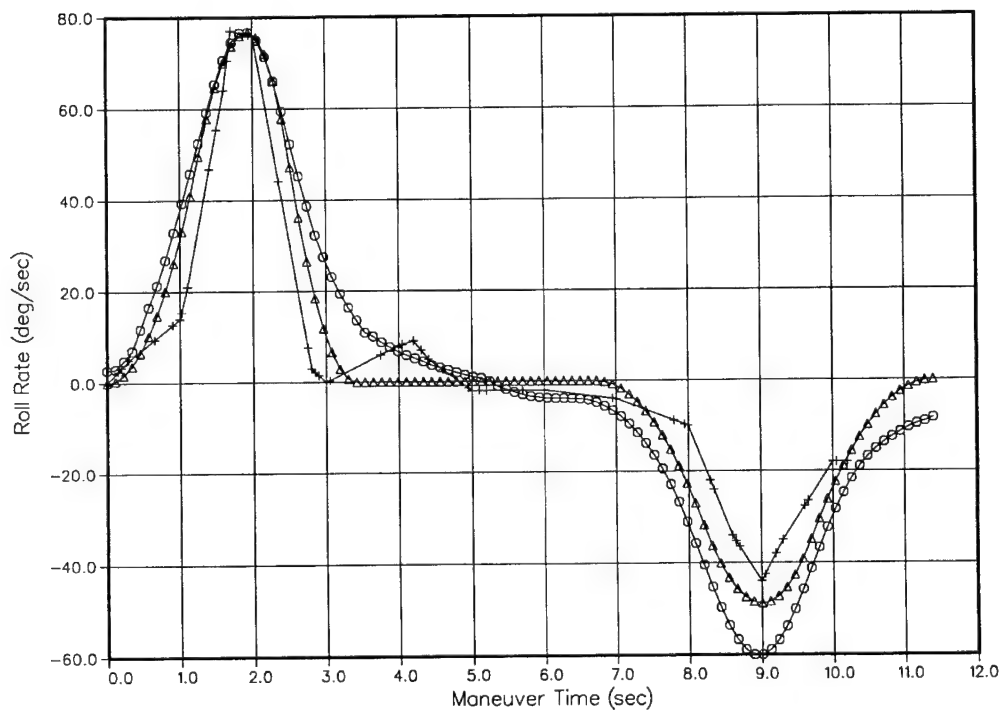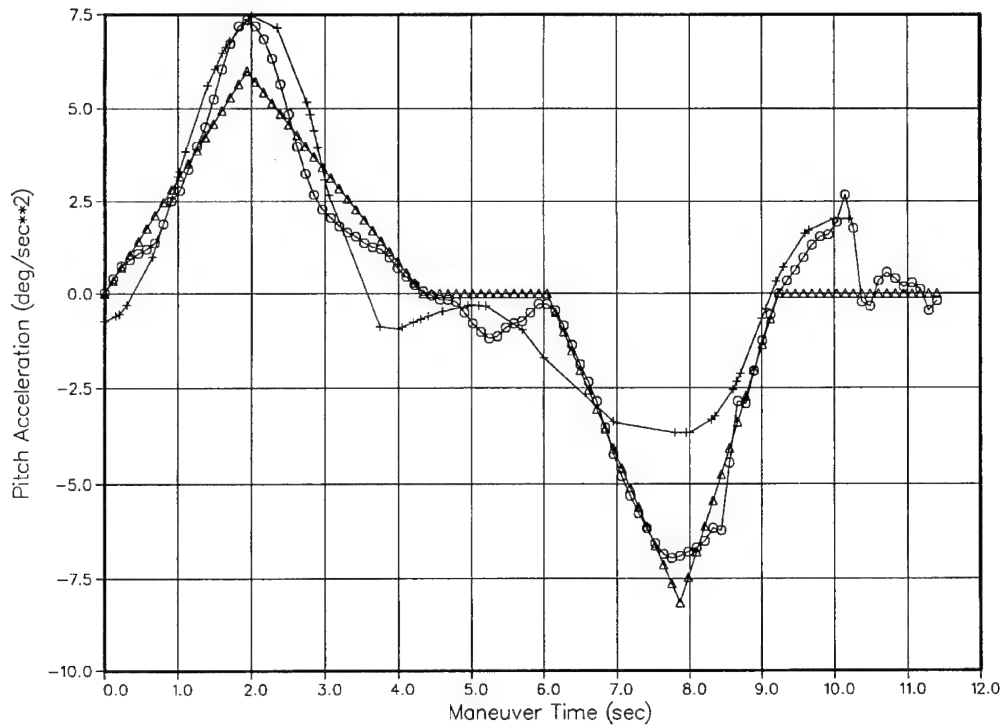

Legend

o = mean
Δ = stand
+ = m_02043

Legend

o = mean
Δ = stand
+ = m_02043

50

6.3.1.3 – CF–18 High g turn Standard Maneuver Reconstituted with CF–18–Maneuver Data (max n_z–level)

Legend

o = mean
Δ = stand
+ = m_02043

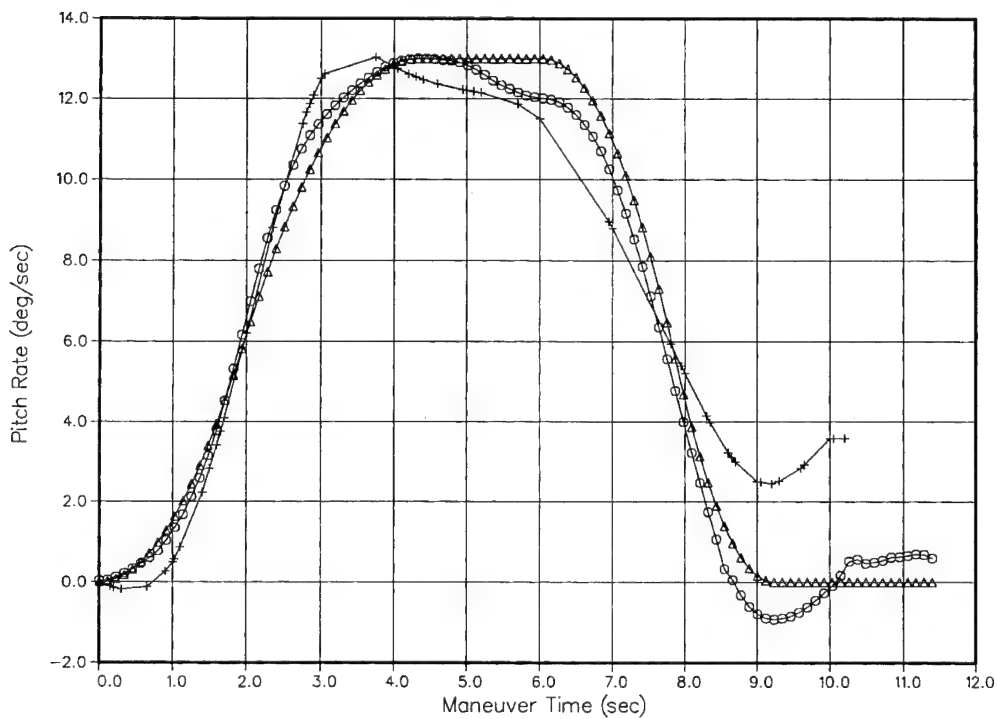Legend

o = mean
Δ = stand
+ = m_02043

6.3.1.3 – CF–18 High g turn Standard Maneuver
Reconstituted with CF–18–Maneuver Data
**(max n_z–level)**

Legend

o = mean
△ = stand
+ = m_02043

Legend

o = mean
△ = stand
+ = m_02043

**6.3.1.4 A   F–16 High g turn Standard Maneuver
Reconstituted with CF–18–Maneuver Data
(max n_z–level)**

Legend

o = mean
Δ = stand
+ = m_02043

Legend

o = mean
Δ = stand
+ = m_02043

6.3.1.4 A   F–16 High g turn Standard Maneuver
Reconstituted with CF–18–Maneuver Data
(max n_z–level)

Legend

o = mean
Δ = stand
+ = m_02043

Legend

o = mean
Δ = stand
+ = m_02043

54

6.3.1.4 A   F–16 High g turn Standard Maneuver
Reconstituted with CF–18–Maneuver Data
(max n_z–level)

**6.3.1.4 B   F–16 High g turn Standard Maneuver
Reconstituted with CF–18–Maneuver Data
(max n$_z$–level)**

6.3.1.4 B   F–16 High g turn Standard Maneuver
Reconstituted with CF–18–Maneuver Data
(max n_z–level)

Legend

o = mean
Δ = stand
+ = m_02043

Legend

o = mean
Δ = stand
+ = m_02043

6.3.1.4 B   F–16 High g turn Standard Maneuver
Reconstituted with CF–18–Maneuver Data
(max n$_z$–level)

Legend

o = mean
Δ = stand
+ = m_02043

Legend

o = mean
Δ = stand
+ = m_02043

58

**6.3.1.5   F–16 Barrel roll Standard Maneuver
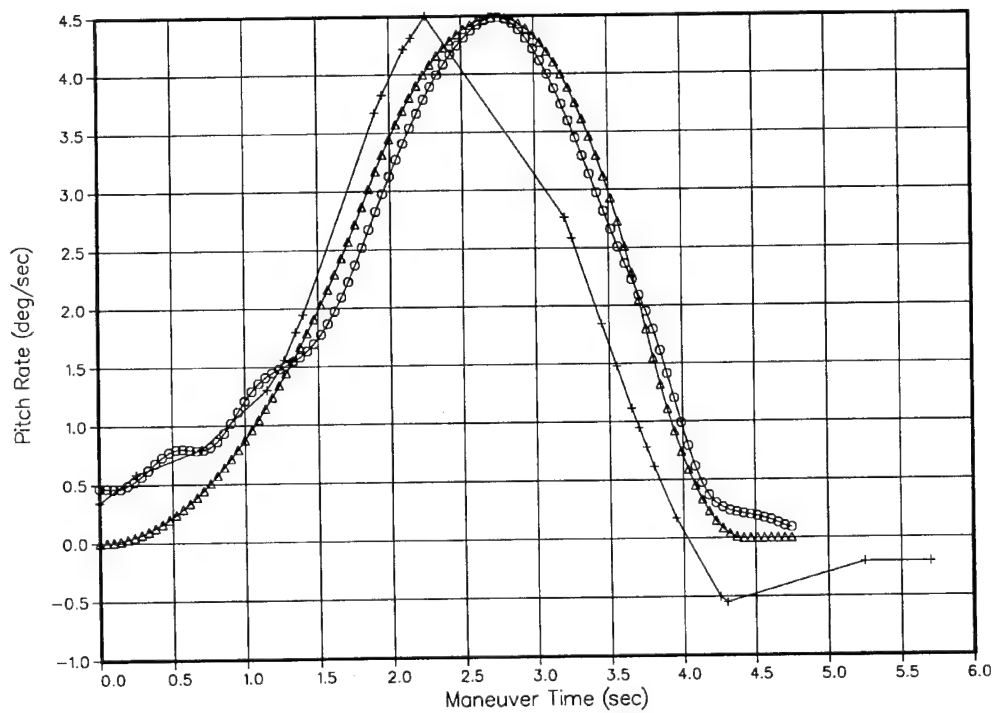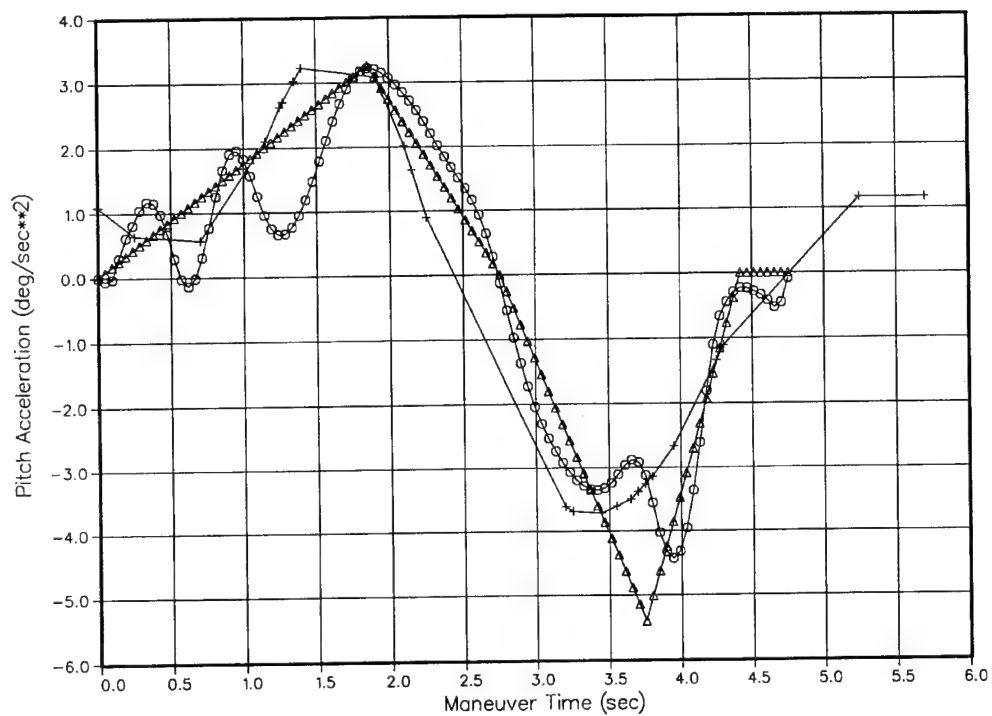Reconstituted with CF–18–Maneuver Data
(max roll rate)**

Legend

o = mean
Δ = stand
+ = m_05523
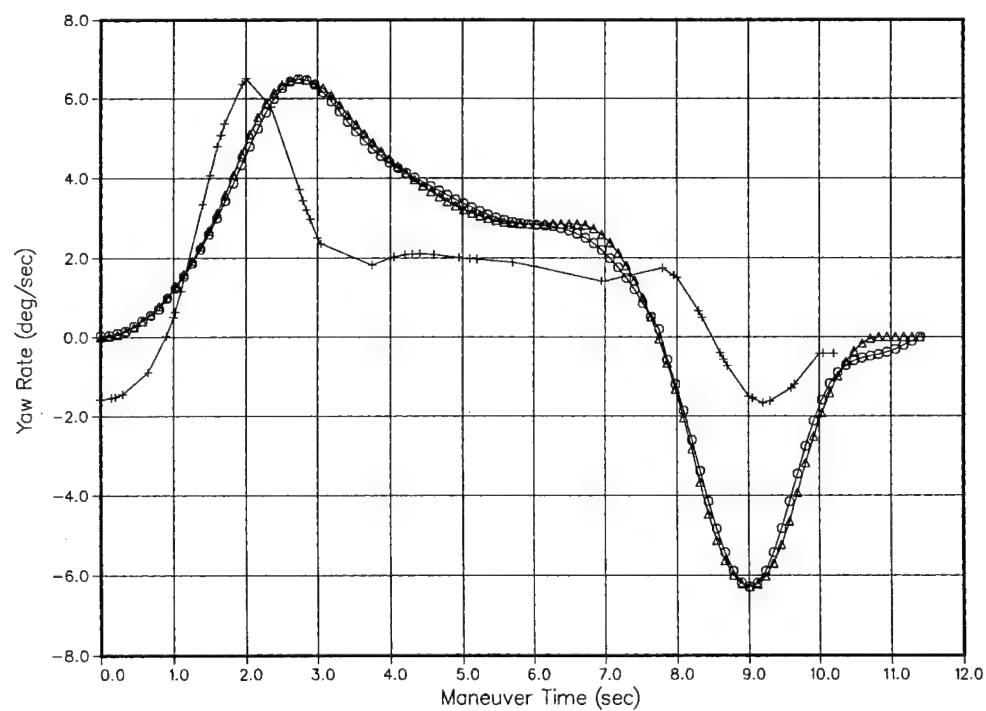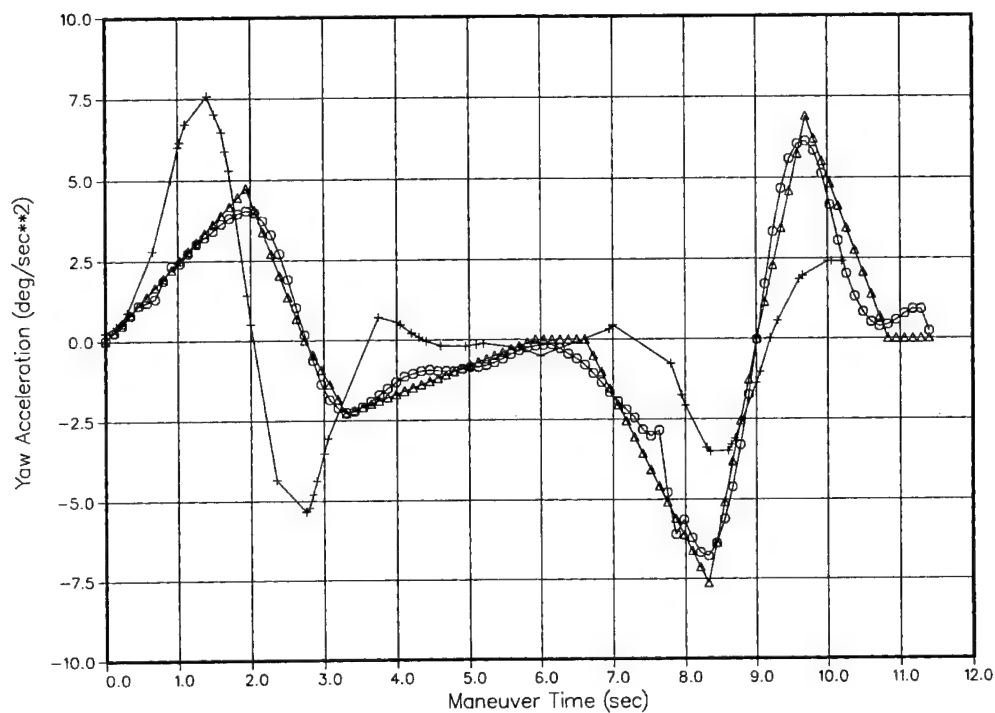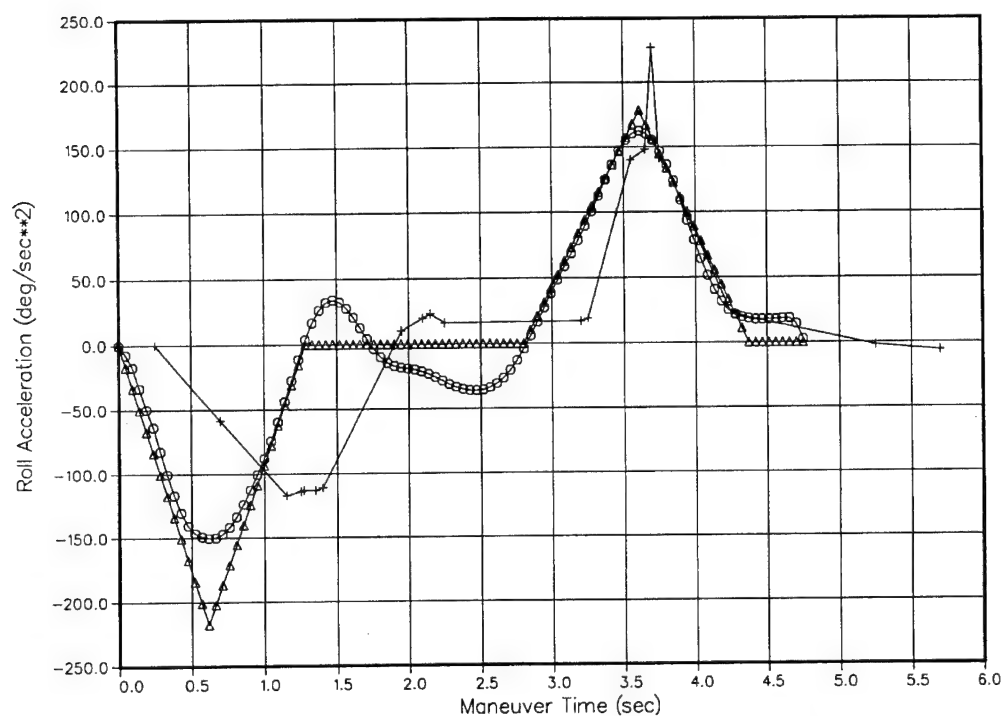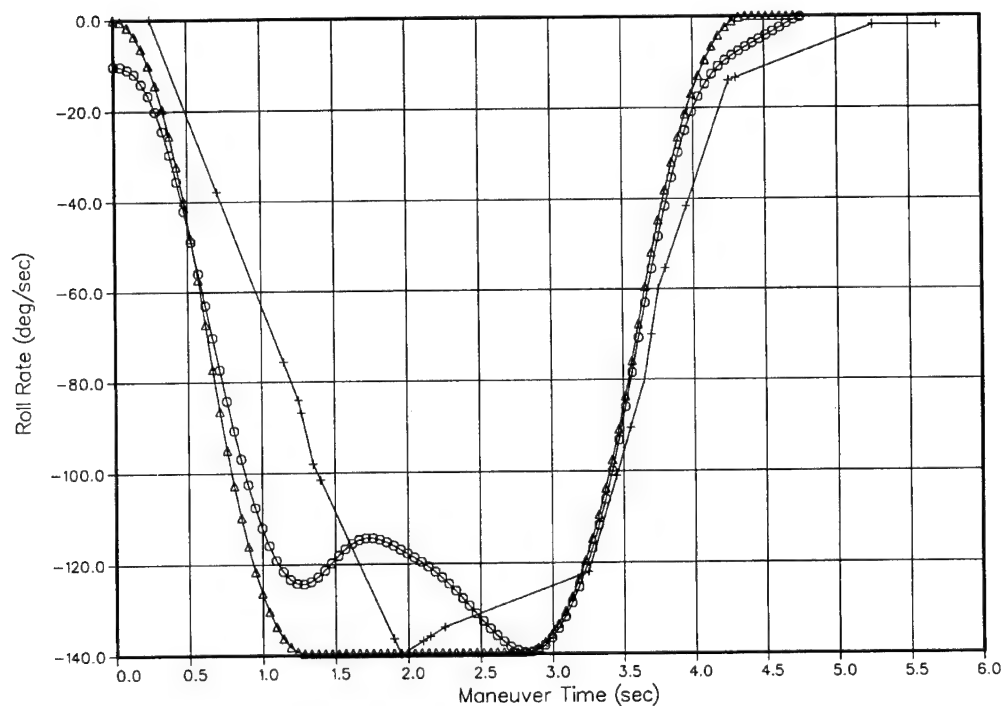
Legend

o = mean
Δ = stand
+ = m_05523

6.3.1.5 **F–16 Barrel roll Standard Maneuver**
Reconstituted with CF–18–Maneuver Data
(max roll rate)

Legend

o = mean
Δ = stand
+ = m_05523

Legend

o = mean
Δ = stand
+ = m_05523

60

**6.3.1.5   F–16 Barrel roll Standard Maneuver
Reconstituted with CF–18–Maneuver Data
(max roll rate)**

Legend

o = mean
Δ = stand
+ = m_05523

Legend

o = mean
Δ = stand
+ = m_05523
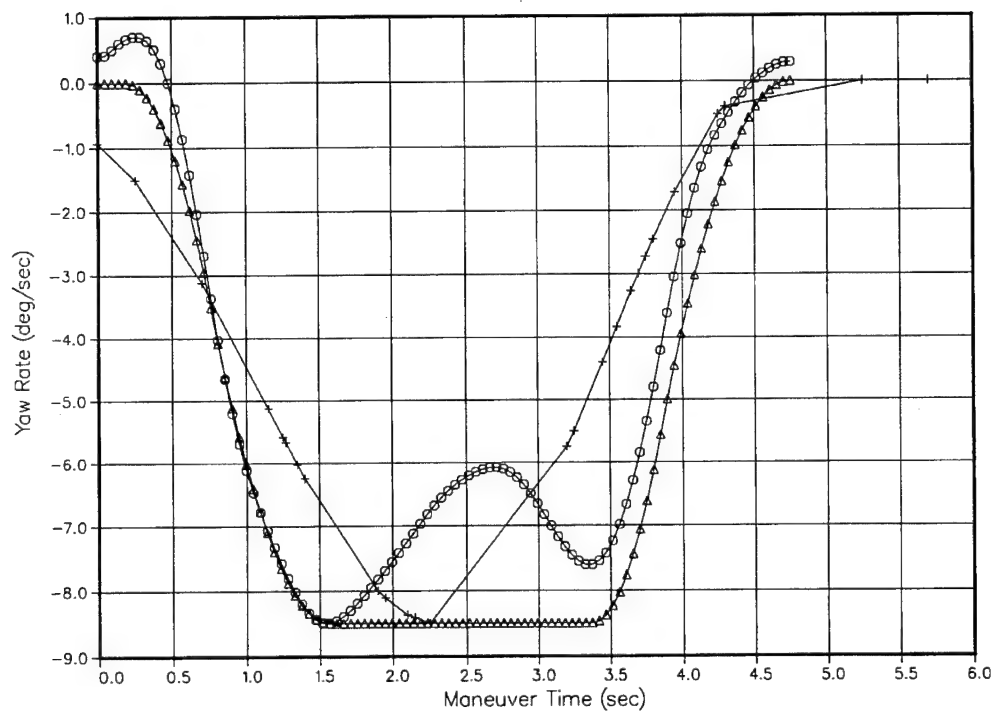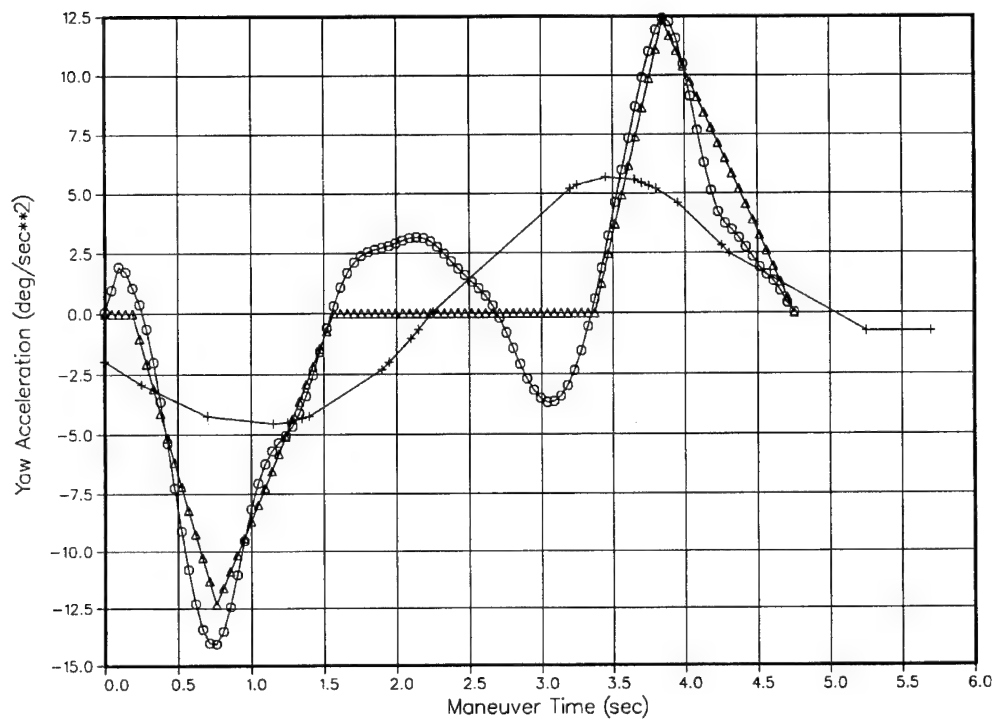
6.4 WG.27 – Loads Comparison

An essential activity of WG.27 was a limited demonstration study which compared the loads calculated using the maneuver model from the reconstituted parameters to actual measured loads for a selection of maneuver types. The full process requires access to measured flight loads data and to aerodynamic and control system data for a selected aircraft type. Non–dimensionalized data for the maneuver types to be considered is also required. In practice, this was beyond the scope of WG.27 and an alternate approach that could be accomplished within the time restrictions of the WG.27 mandate had to be found.

A reduced program (Section 6.0) was defined which used available CF–18 loads data and a Bombardier/ Canadair Defence Systems Division (BI/CDSD) loads calculation methodology. Canada was unable to release the CF–18 aerodynamic and control system data that would allow the use of the maneuver model.

The procedure used is shown in Figure 6.0 and is summarized as follows:

- Two maneuvers (one with higher symmetrical and the other with higher asymmetrical parameters) were chosen from the data set of manoeuvres for which fully balanced loads had been determined and verified under the IFOSTP program as the basis of comparison. Also available were the time histories of the aircraft parameters.

- Using Standard Maneuver time histories as non–dimensionalized maneuver descriptions determined from F–16 data and the maneuver definition for the selected maneuvers, parameter time histories were determined for the maneuver.

To accelerate the loads comparison process, for the purposes of WG.27 these methodologies were used to calculate balanced loads conditions for the selected maneuvers based on the reconstituted parameters. These calculated loads were compared to "actual" loads for the same maneuver which had been determined under the IFOSTP program.
The comparison has been demonstrated only for the High g turn maneuver derived from F–16 and compared to CF–18 actual loads in Chapter 6.4.2. The results are discussed in Chapter 7 B.

6.4.1   BI/CDSD Loads Calculation Methodology

As part of the joint Canadian–Australian CF–1 8 International Follow–On Structural Test Program (IFOSTP), methodologies were developed to calculate fully balanced loads conditions at the major interfaces from the input parameters available from the CF–18 MSDRS system. The development of these methodologies was sponsored by the Canadian Department of National Defence and required an extensive effort at BI/CDSD. An extensive and successful validation program was pursued using flight test data from the Canadian Forces Aerospace Engineering Test Establishment and the Royal Australian Air Force Aircraft Research and Development Unit.

The Data available from MSDRS for the loads derivation was the following:

> Maneuver ID (MANID)
> Time
> Indicated Air Speed
> Altitude, Nz at cg (MSDRS triggers, ± 1/sec)
> Nzdot (Nz rate of change)
> Angle of Attack (AOA)
> Roll, Pitch rate (p,q) (MSDRS 1/sec + triggers)
> Roll, Pitch accelerations (computed)
> Total weight
> Fuel Weight
> Pitch angle
> Roll angle
> Lateral accelerations Ny
> Rudder Pedal Force
> Wing Root Fold strain
> Hstab, Vstab strain
> L/R Power Lever Angle

Using this data, aerodynamic and inertia loads were generated.

During the development phase of the load process, it became evident that the accuracy of some of the recorded flight parameters needed improvement. This is discussed next.

Due to the accuracy limitation of the MSDRS system, the following flight parameters required correction:

Angle of Attack (AOA)
The AOA resolution on the MSDRS system is 1.4 degree, which is very crude especially when transonic effects begin to appear. The corrections to the AOA are to center the (+/–0.7 deg) and to smooth it.
When correlating MSDRS AOA with that measured during flight test, it was observed that true AOA and MSDRS AOA were lagging in time. True AOA and MSDRS AOA were not recorded at the same time.

Normal Load factor Nz
It was noted that the MSDRS Nz was not recorded at CG but at the INS location, that is under the pilot seat.
Moreover, MSDRS Nz was lagging with respect to Nz CG as recorded during flight testing.

Sideslip Angle
The sideslip angle was calculated analytically using other parameters that had inherent inaccuracies. A maximum limit of 8 degrees which was decreased with dynamic pressure was put on the calculation since higher sideslip would be encountered during spin conditions only.

Pitch and Yaw RATES
Pitch and yaw rates required interpolation since they were recorded only once per second.

Angular Accelerations
All the angular accelerations were computed from corresponding rates.

Control Surface Positions
Since the aerodynamic loads depend also on the control surface positions, these needed to be computed. The CF–18 is equipped with a feedback control system, therefore to compute control surfaces positions, the flight control system was modelled. Some severe accuracy limitations were observed for very abrupt asymmetric maneuvers due to the inaccuracy of the lateral stick position information which– was determined by interpolation from 1 hz sampling rate to 20 hz .

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Interface Loads Derivation

The step after reading input data is the determination of the following interface loads: wing root, forward fuselage and aft fuselage.

These interface loads were used with transfer functions to derive stress histories at fatigue critical locations.

Interface loads are also computed at wing/control surfaces interfaces in order to get proper aerodynamic distributions on the wing.

The derivation of these loads is a two step process:

- aerodynamic loads computations

- combination of inertia and aerodynamic loads.

The derivation of aerodynamic interface loads was based on using flight test data from which the aircraft inertia was removed.

That is,

$$L_{aero} = L_{tot} - K_I \ddot{x}$$

where K_I represents unit inertia loads.

These loads are then written in a non–dimensional coefficient form by dividing by the dynamic pressure.
It has been observed that in most cases, the interface loads coefficient can be split into symmetric and asymmetric components, that is:

$$L_S = 1/2 \, (L_L + L_R)$$

$$L_A = 1/2 \, (L_L - L_R)$$

The wing root bending moment symmetric loads depend on the same flight parameters for both symmetric and asymmetric maneuvers. These parameters are not related to the asymmetric character of a maneuver and thus decoupling can be used to derive appropriate aerodynamic load trends that make the essence of the interface aerodynamic loads data base.

Symmetric coefficients relations can be written as:

$$L_S = f \, (AOA, \, Cn, \, Mach, \, Flaps)$$

It should be noted that for some components such as the wing root torque, the rate of change of Nz plays a role in the correlation due to some inherent lag in trailing edge flap scheduling. For some load components, such as the trailing edge flap component on the wing, uncoupling can not be performed.

Asymmetric aerodynamic coefficient trends can be formulated as follows:

$$L_A = DP$$

where D represents coefficient matrix which is function of AOA and Mach, while P represents asymmetric parameters such as a roll rate, differential control surface positions etc...

Asymmetric component of loads depends on differential values and on roll rate and acceleration.

Due to the inaccuracy of the lateral stick position prediction, load trends that were using differential aileron such as the wing root torque was modified to rely on more accurate differential independent variables such as the horizontal stabilator differential MSDRS strains.

Once the aerodynamic interface loads are computed, the aircraft was pre–balanced. Inertial and aerodynamic loads were made equal by modifying interface aerodynamic loads according to the standard deviation of a given trend.

Load Distribution Generation

The load distribution generation consists of assembling pre defined aerodynamic load distributions (pressure distributions) using an optimization procedure to match the interface aerodynamic loads. Unit distributions were generated using wind tunnel testing or doublet lattice (DLM). Unit loads –are also generated for:

- flap deflections
- rolling
- aeroelastic effects

These basic distributions were modified to match the calculated interface aerodynamic loads. This procedure is called factoring. However, in some cases, due to the statistical basis of the interface loads, some small inconsistencies between interface loads would create skewed, unrealistic final distributions. In order to avoid that situation, an intermediate step called flight parameter optimization was added. Then the aerodynamic distributions were modified using a least squares procedure.

The next step was to combine inertia distributions computed from a stick model that included the aircraft configuration and fuel weight.

Interface Loads Validation

The loads are considered valid when the prediction lies inside the aerodynamic coefficient trend standard deviation derived from various flight tests.

6.4.2 CF–18 Loads Derived from F–16 High g turn
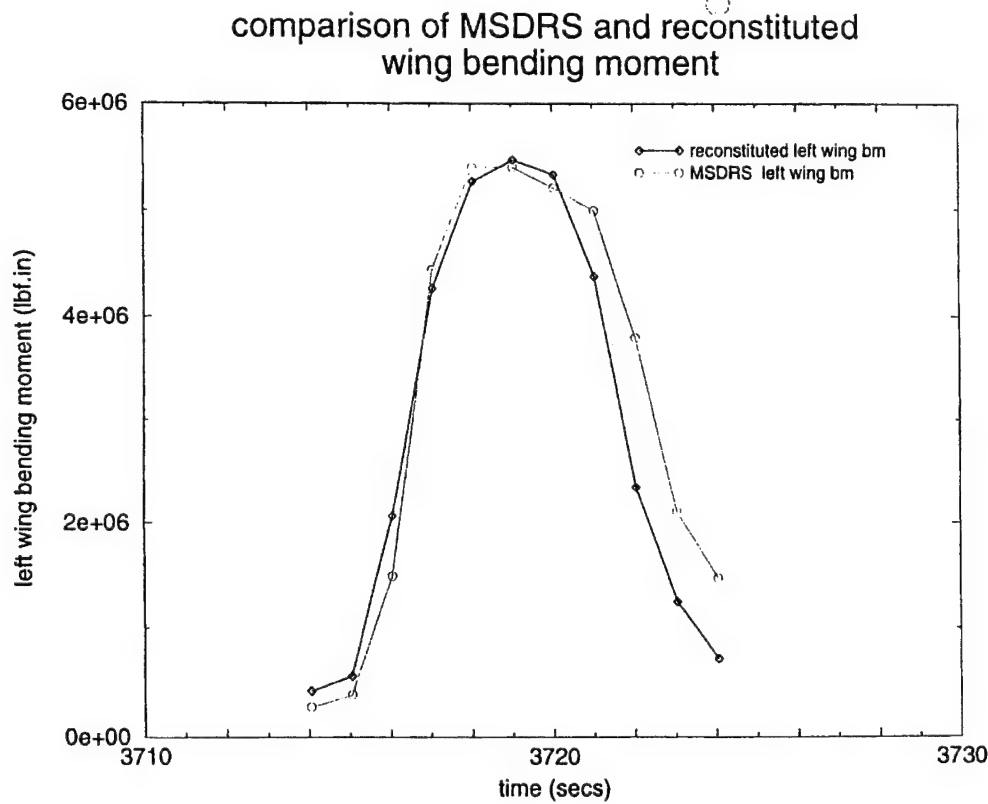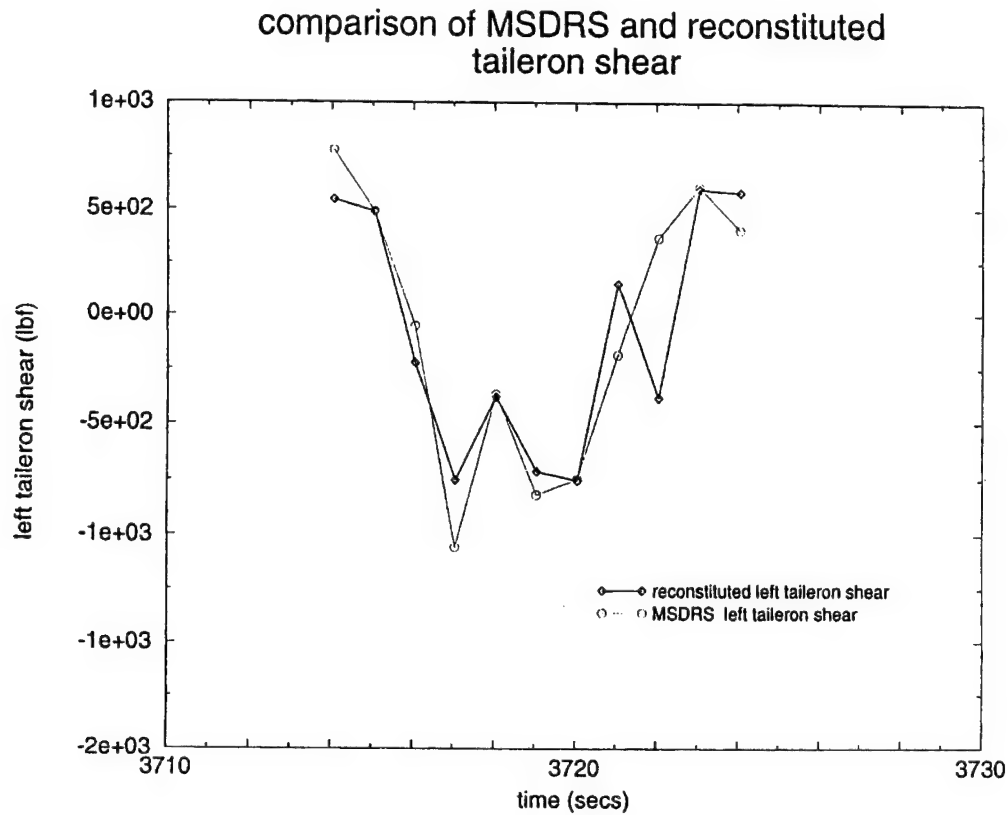### Standard Maneuver (max n_z–level)

comparison of MSDRS and reconstituted
aft fuselage bending moment
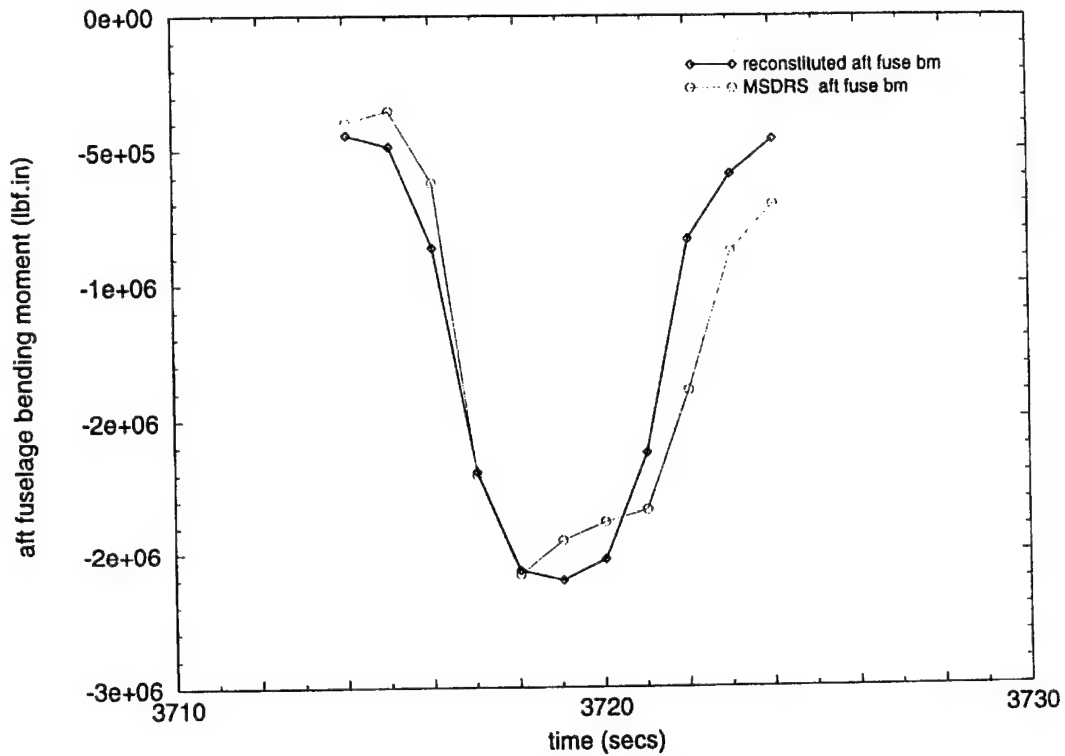
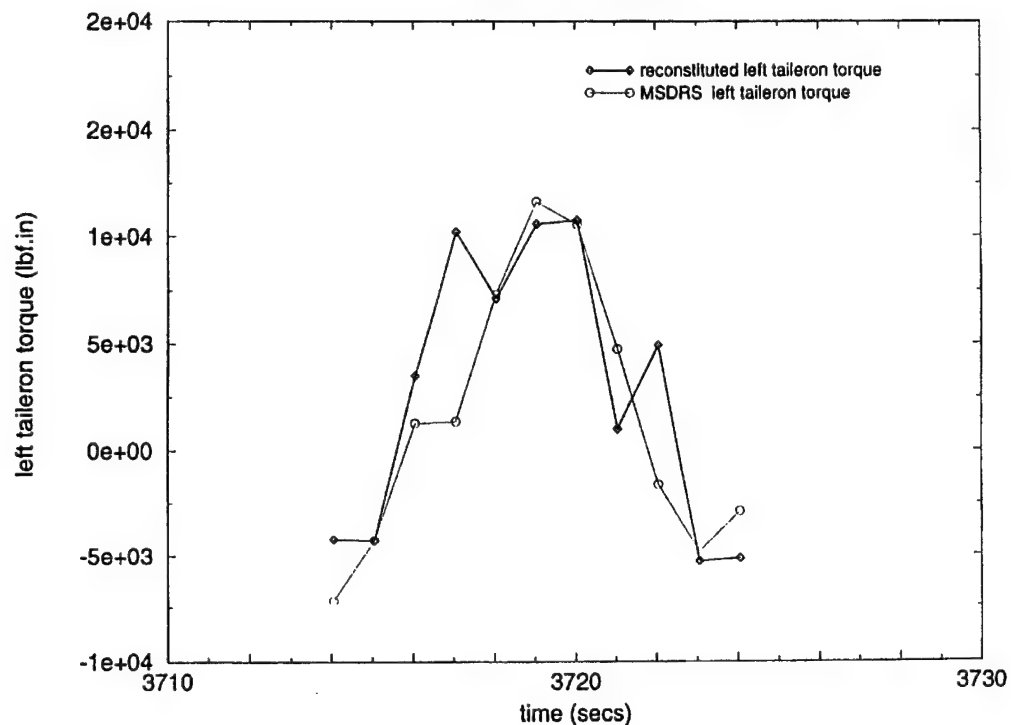## comparison of MSDRS and reconstituted
forward fuselage bending moment
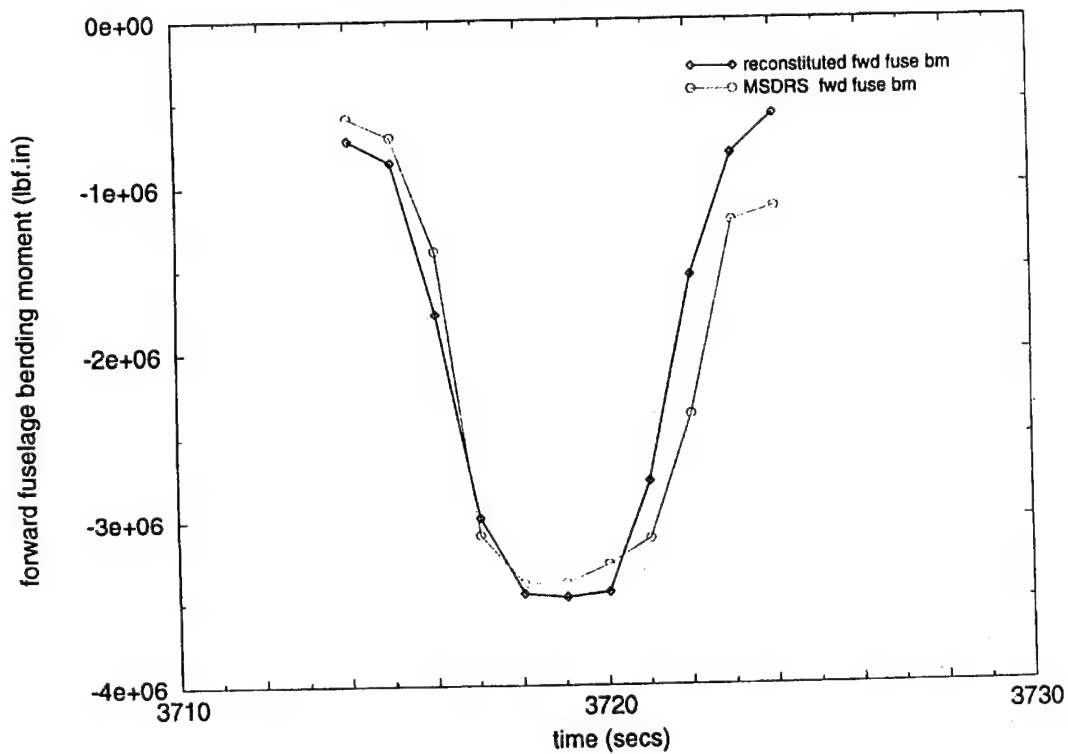
6.4.2 – CF–18 Loads Derived from F–16 High g turn
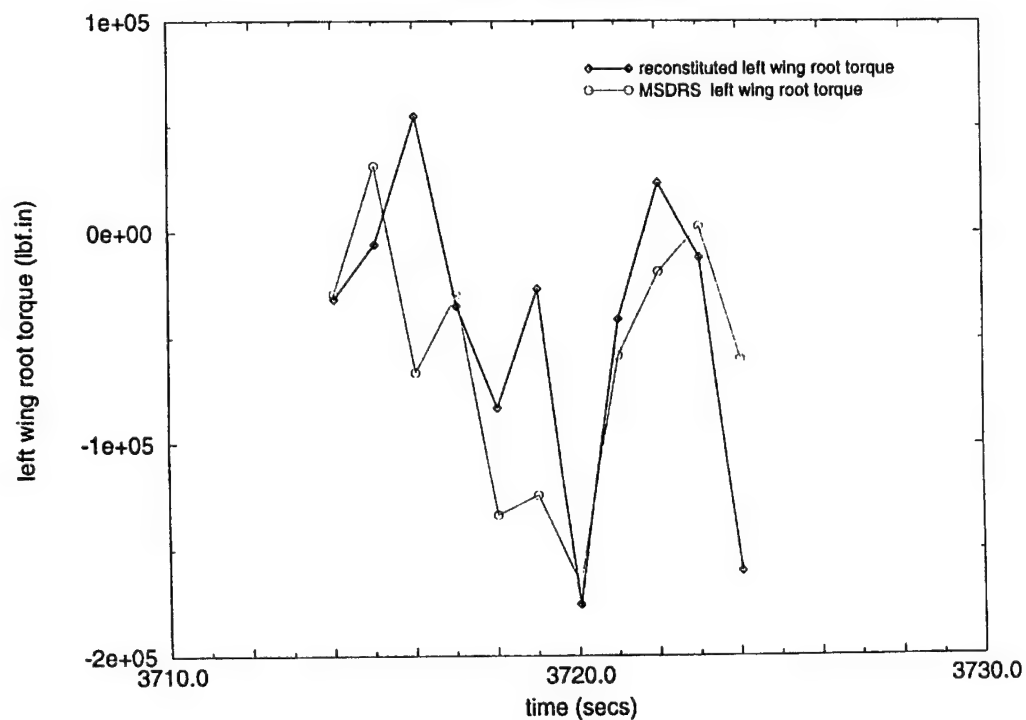**Standard Maneuver (max n_z–level)**

comparison of MSDRS and reconstituted taileron shear

comparison of MSDRS and reconstituted wing bending moment

6.4.2 – CF–18 Loads Derived from F–16 High g turn
Standard Maneuver (max n_z–level)

comparison of MSDRS and reconstituted
taileron torque

comparison of MSDRS and reconstituted
wing root torque

6.5 WG.27 – Results – Discussion

6.5.1 Definition of Standard–Maneuver

The procedure for defining a Standard–Maneuver is shown in Chapter 5.3 . For an individual aircraft type, this procedure is applied for all maneuver types to be considered.

For the determination of a Standard–Maneuver based on data from a group of aircraft types, several procedures are possible. For the maneuver type considered, the data of all the aircraft are examined and maneuvers of the type being considered are identified, normalized and verified.
From this data, the Standard–Maneuver time history can be determined by different processes:

       (1) Applying all recorded maneuver time histories which have been verified of all aircraft types.

       (2) Applying all mean maneuver time histories of all aircraft types.

       (3) Applying all Standard–Maneuver time histories of all aircraft types

The resulting Standard–Maneuver time history is the same independent of the process used because the same evaluation procedure is applied.

WG.27 used procedure (3) because this process keeps the Standard–Maneuver time history for each aircraft type separate. This allows for better judgment of the influence on the time history concerning correlation of the parameters for different aircraft types.

In addition, procedure (3) is appropriate for the induction of criteria for the idealization of the maneuver time history to obtain the most critical maneuver time history representative of all aircraft types.
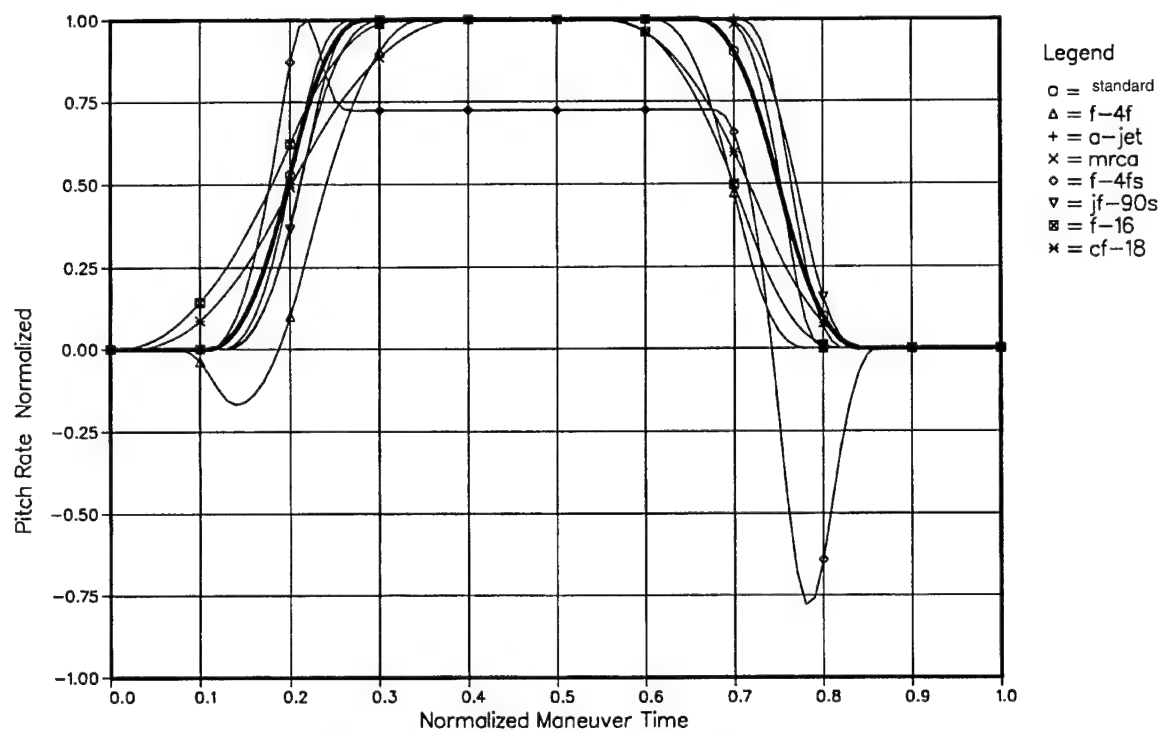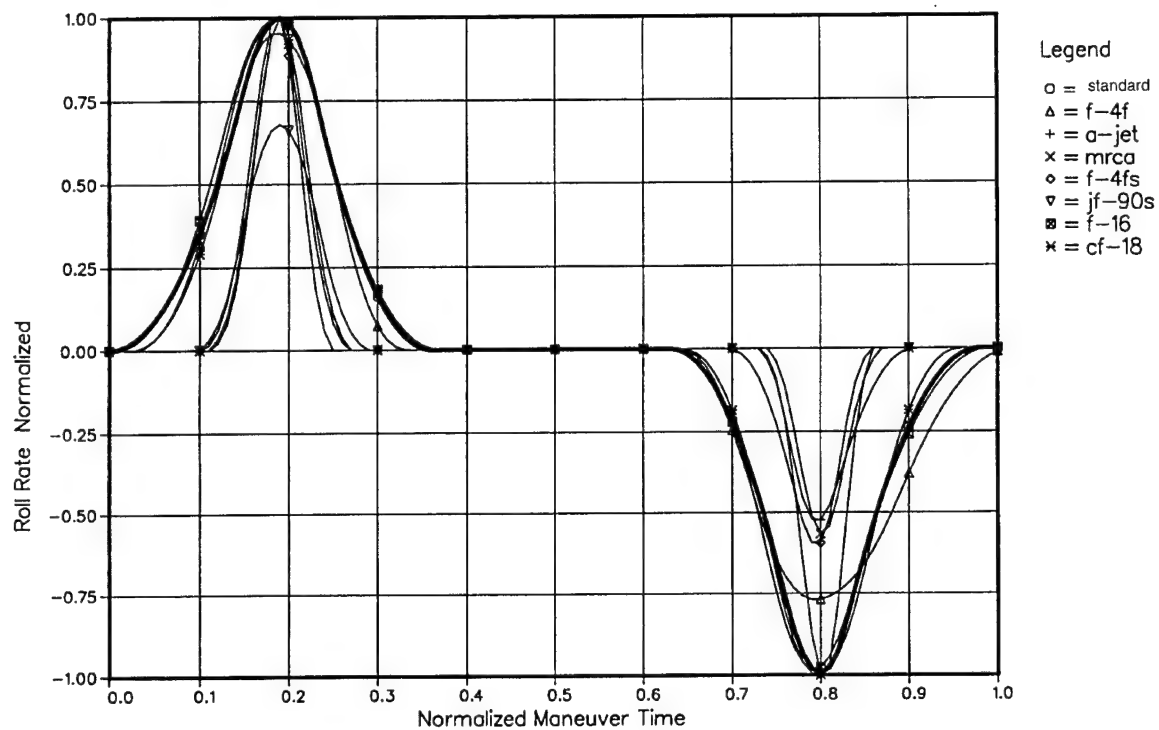
6.5.1.1 Definition of Standard–Maneuver independent of Aircraft–type for the High–g–turn Maneuver

To illustrate the process, the definition of a Standard–Maneuver high–g–turn was performed based on the Standard Maneuvers derived for different aircraft using the process outlined in the flow chart in Figure 5.3 .

- Input: Standard Maneuver of different aircraft reconstituted with the specific aircraft reconstitution factors

- Determination of Mean Values

- Idealization: An idealization is performed

– To cover the most extreme peaks of the control surface deflections possible, the most extreme accelerations in roll (p), pitch (q) and yaw (r) are used.
These values are obtained by linearization of the acceleration time history in a way such that the same response of the aircraft is obtained.

– To obtain a short but intensive input of control deflections at the initiation of the maneuver and a short but intensive input of control deflection at the completion of the maneuver keeping compliance with the aircraft attitude parameters for the required maneuver type. Between initiation and completion of the maneuver, control surfaces should be deflected a way that aircraft accelerations are more or less constant.

– For the High–g–turn maneuver the criteria applied are:
     The peak value of the rate (p) is the maximum for the first peak at initiation as well as for the second peak at completion of the maneuver.

- After tuning of the idealized time history, the Standard Maneuver Time History independent of aircraft–type is determined as shown in Chapter 6.5.2

6.5.2 **Comparison of normalized Standard Maneuver for different aircraft types and definition of Standard Maneuver independent of aircraft type for High–g–turn Maneuver**

Legend

o = standard
Δ = f−4f
+ = a−jet
× = mrca
◊ = f−4fs
▽ = jf−90s
⊠ = f−16
✗ = cf−18

Legend

o = standard
Δ = f−4f
+ = a−jet
× = mrca
◊ = f−4fs
▽ = jf−90s
⊠ = f−16
✗ = cf−18

6.5.2   **Comparison of normalized Standard Maneuver
for different aircraft types and definition of
Standard Maneuver independent of aircraft type
for High–g–turn Maneuver**
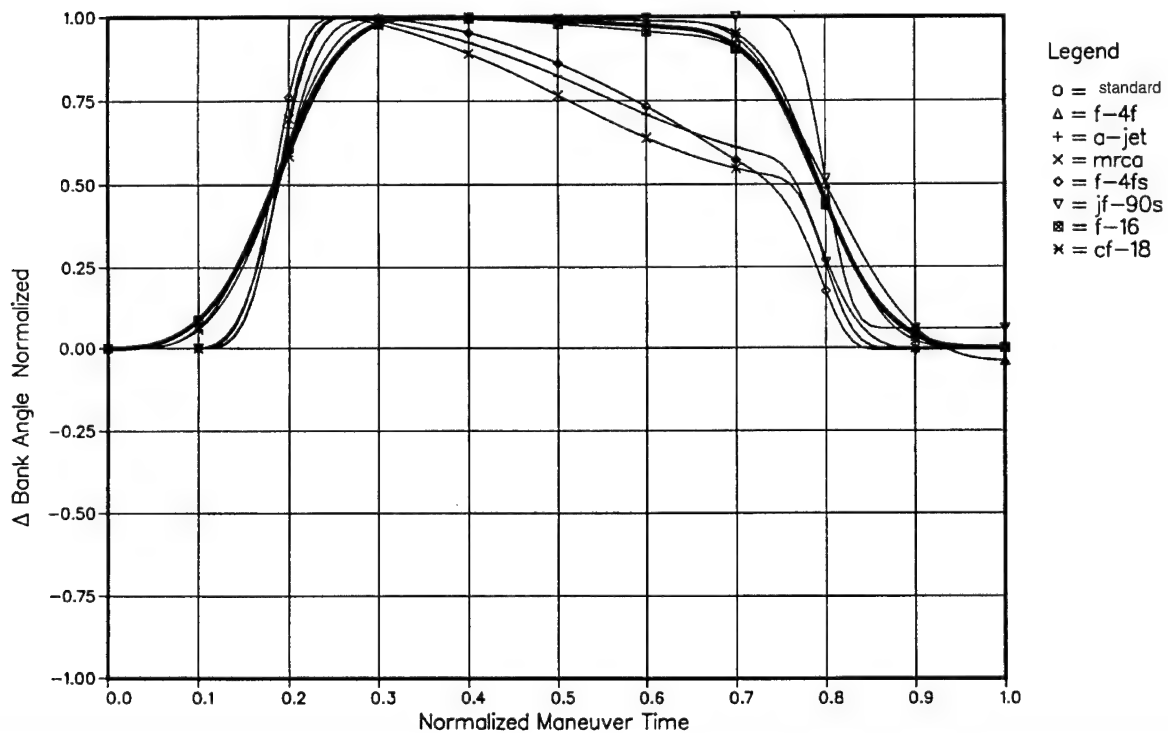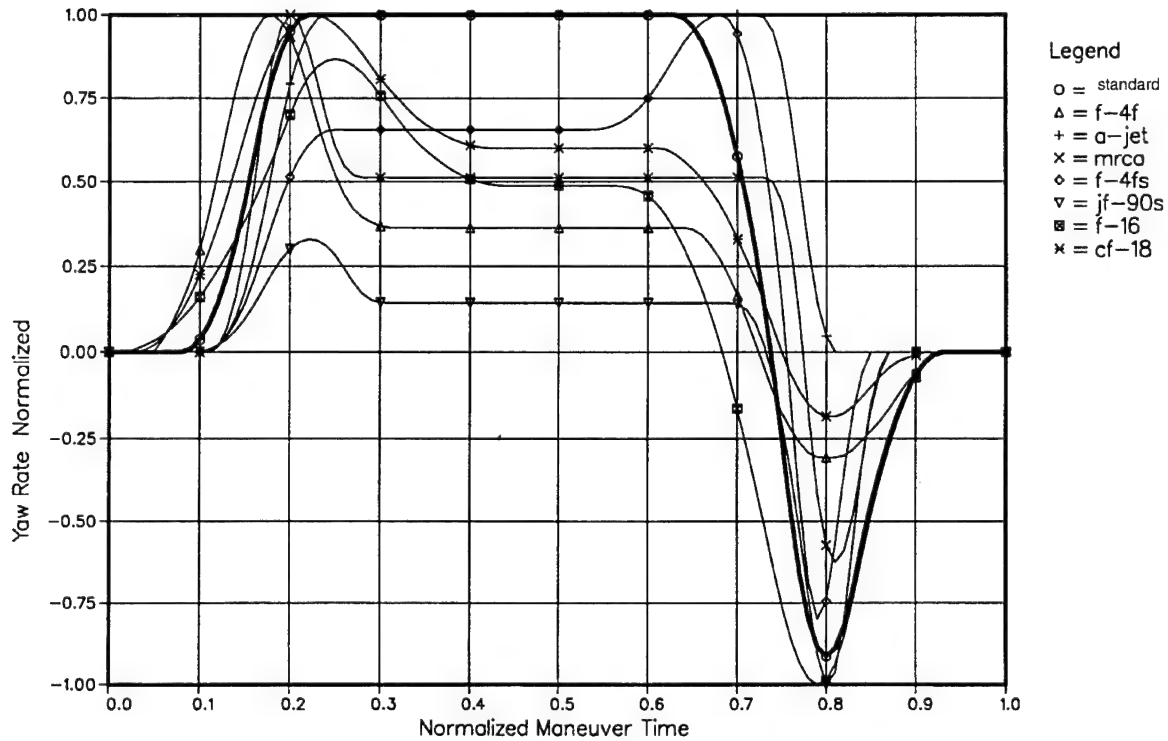
6.6 Application of the Maneuver Model

Determination of extreme operational loads GAF – F–4F

The operational parameters of the standard maneuver are considered as mean parameters.

For deriving the extreme maneuvers, the main parameters of the standard maneuver are scaled up to the boundary conditions to be obtained. The values for the parameters of the boundary conditions (T_{MAN}, n_z, n_y, Φ) can be derived from extreme value distributions or can be assumed with reference to design parameters required by specifications (MIL–Spec.). In the following example the boundary conditions were applied corresponding to MIL–A–008861 shown in Table 1 .

Stations for load analysis

Table 1 shows the mean values and the assumed corresponding extreme values for the maneuver time (T_{MAN}), load factors (n_z, n_y), the angles of bank (Φ).

For determination of the extreme values the maximum values of the mean parameters for the 5 analyzed maneuvers have been scaled up to the load factors required by MIL–8861. The determination of the extreme maneuvers is performed by the same procedure as for the mean maneuvers, but applying extreme boundary conditions.

	T_{MAN} (sec)		n_z		n_y		Φ [°]	
	mean	extr.	mean	extr.	mean	extr.	mean	extr.
FULL AILERON REVERSAL	11	11	5.0	6.5	0.4	0.6	100	100
HIGH–G–BARREL ROLL O.T.	20	5.6	4.0	5.0	0.12	0.3	360	360
HIGH–G–BARREL ROLL U.N.	20	6.8	3.5	4.5	0.12	0.4	360	360
HIGH–G–TURN	8	5.3	5.0	8.0	0.25	0.5	90	90
ROLLING ENTRIES + PULL OUT	17	7.5	5.0	6.5	0.15	0.4	100	100

Table 1 Model Parameters for Load Analysis

For the extreme maneuvers the loads on the following main structural components have been analyzed as shown the following sketch.

– bending right on wing root

– bending left on wing root

– bending vertical on rear fuselage

– bending lateral on rear fuselage

– shear on horizontal tail root

– shear on vertical tail root
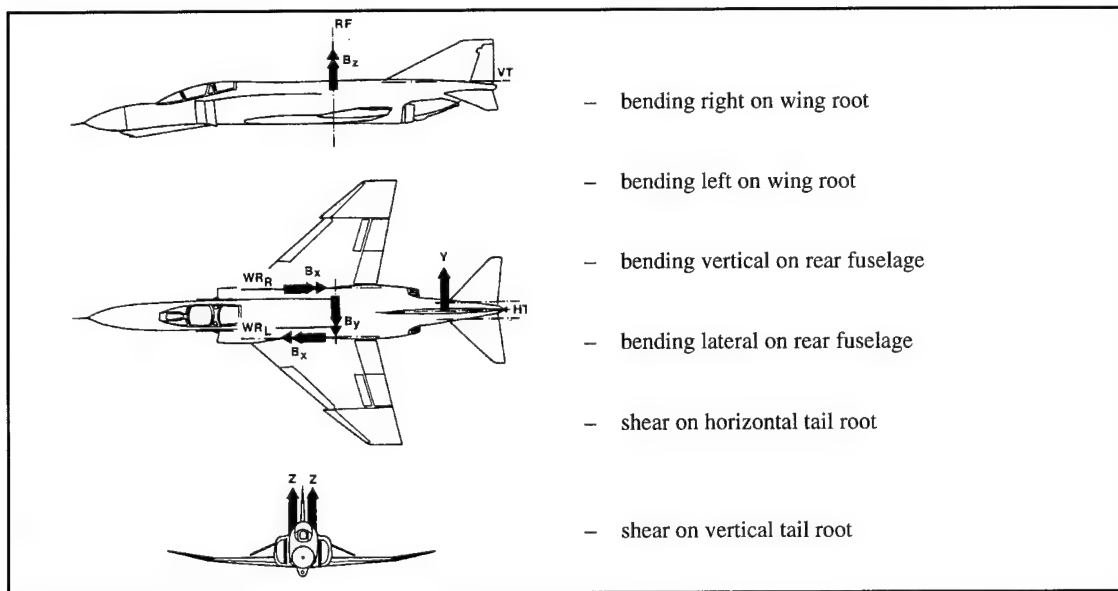
For the High–g–turn maneuver, the extreme operational maneuver parameters are plotted in Figure 1–4, the extreme operational loads in Figure 5–7, and the control deflections in Figure 8.

The parameters and loads are plotted as normalized values versus real time. For the normalization the values are related to the maximum values indicated in the diagrams.
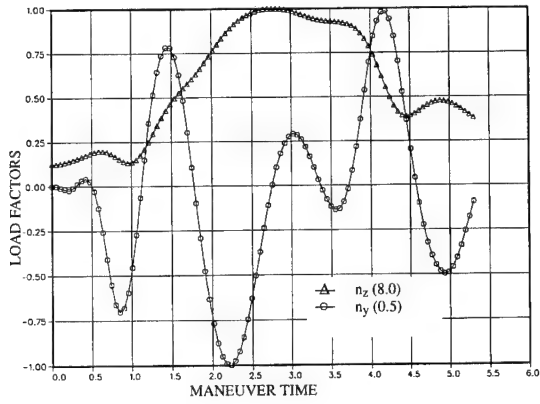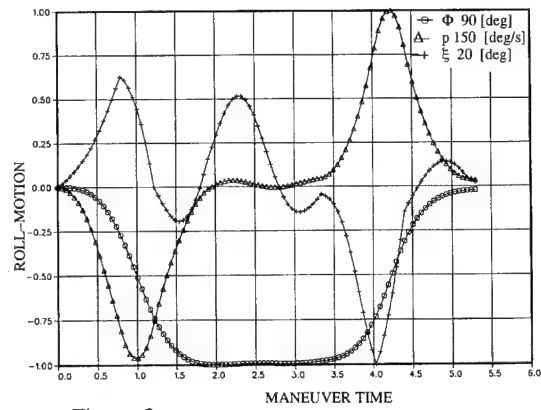
Figure 1

EXTREME OPERATIONAL
PARAMETERS HIGH–G–TURN

LOAD FACTORS

MANEUVER TIME

nz (8.0)
ny (0.5)

Figure 2

EXTREME OPERATIONAL
PARAMETERS HIGH–G–TURN

ROLL–MOTION

MANEUVER TIME

Φ 90 [deg]
p 150 [deg/s]
ξ 20 [deg]
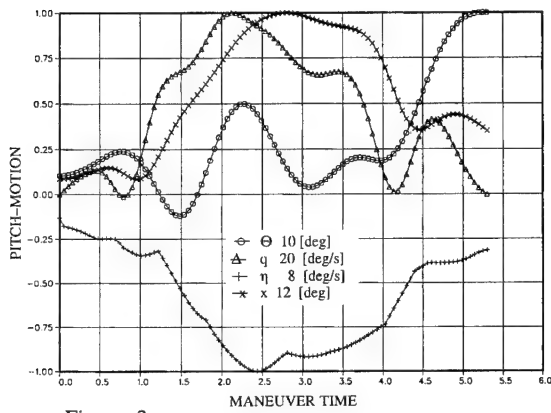
Figure 3

EXTREME OPERATIONAL
PARAMETERS HIGH–G–TURN

PITCH–MOTION

MANEUVER TIME

Θ 10 [deg]
q 20 [deg/s]
η 8 [deg/s]
x 12 [deg]
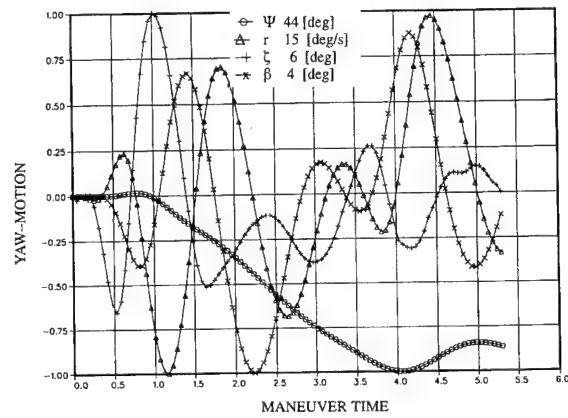
Figure 4

EXTREME OPERATIONAL
PARAMETERS HIGH–G–TURN

YAW–MOTION

MANEUVER TIME

Ψ 44 [deg]
r 15 [deg/s]
ζ 6 [deg]
β 4 [deg]
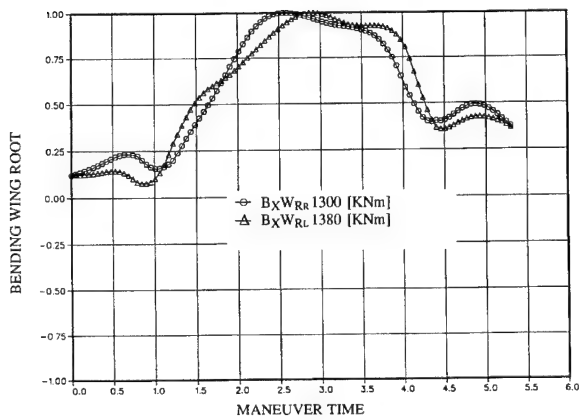
Figure 5

EXTREME OPERATIONAL
LOADS HIGH–G–TURN

BENDING WING ROOT

MANEUVER TIME

$B_X W_{RR}$ 1300 [KNm]
$B_X W_{RL}$ 1380 [KNm]
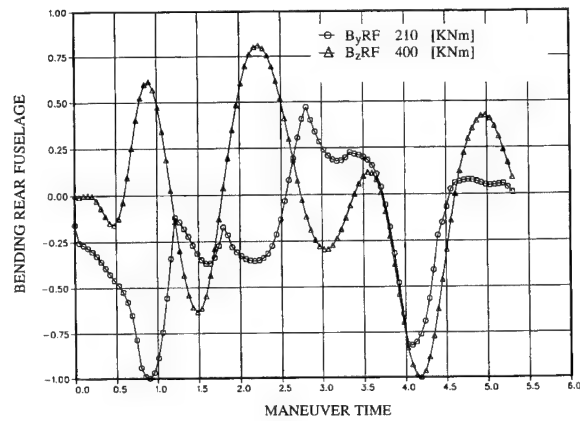
Figure 6

EXTREME OPERATIONAL
LOADS HIGH–G–TURN

BENDING REAR FUSELAGE

MANEUVER TIME

$B_y RF$ 210 [KNm]
$B_z RF$ 400 [KNm]
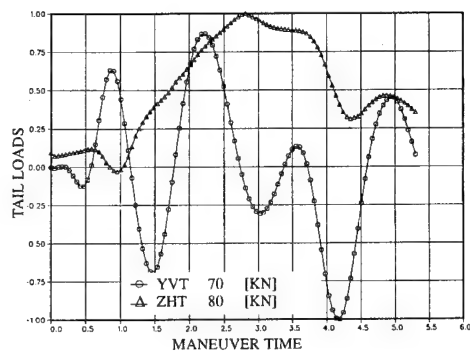
Figure 7

EXTREME OPERATIONAL LOADS
HIGH–G–TURN
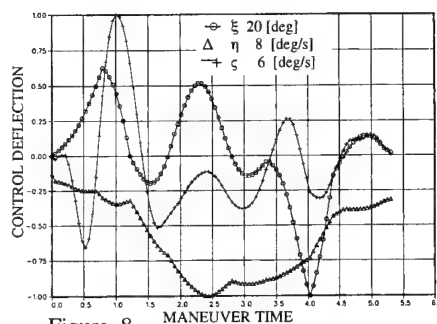
Figure 8

EXTREME OPERATIONAL CONTROL
DEFLECTIONS HIGH–G–TURN

Figure 9

Figure 10

Figure 11
EXTREME OPERATIONAL CONTROL DEFLECTIONS
OPERATIONAL MANEUVERS

As examples, the evaluation of operational maneuvers has been performed for the following 5 maneuvers:

– full aileron reversal

– high–g–barrel roll over the top

– high–g–barrel roll underneath

– high–g–turn

– rolling entries + pull out

The control deflections plotted in Figure 9 – 11 show an interesting course for the five individual operational maneuvers. In three of the maneuvers, alternating control deflections have been found, especially roll– and yaw controls.

In detail:	Numbers of alternating deflections	
	aileron	rudder
high– g– turn	4	4
full aileron reversal	3	3
rolling entries	2	2

The control deflection course in high–g–barrel rolls occurs in one direction only. For all maneuvers, the pitch control deflections show a moderate deflection history.
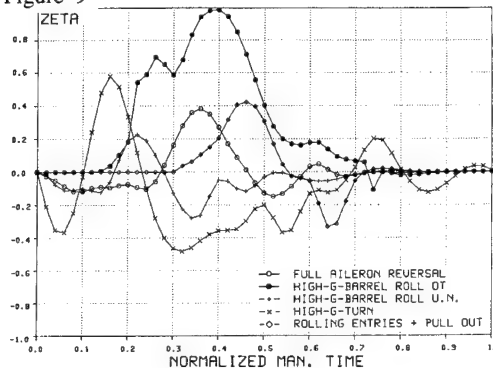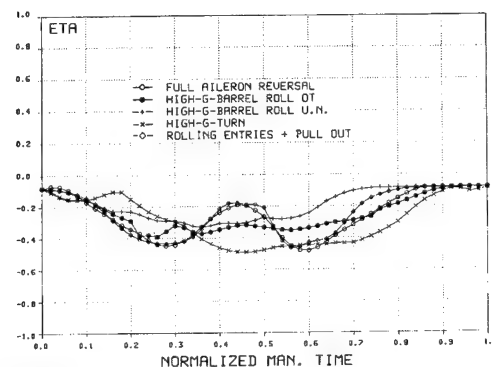
Concerning the vertical load factor shown in Figure 12, the most alternating of the n_z histories are caused by the rolling entries and the full aileron reversals. In Figure 13 – 17 the structural loads on the main components versus maneuver time are plotted. Looking at the correlations and alternations, the following observations may be stated:

– the wing root bending correlates to the vertical load factor (Figure 12 and 13)
– the lateral bending on the rear fuselage shows a similar time history as the load on the vertical tail (Figure 15 and 17)
– the horizontal tail loads changing the most are found at rolling entries and full aileron reversal maneuvers. During these maneuvers two load peaks occur consecutively (Figure 16)
– the vertical tail loads alternating the most are obtained at full aileron reversal and high–g–turn maneuvers (Figure 17). For each of these maneuvers at least four load peaks can be counted.
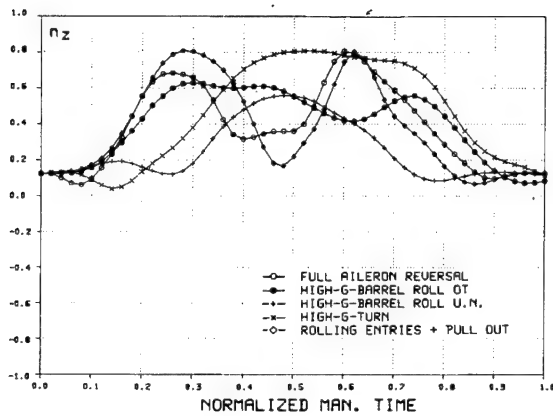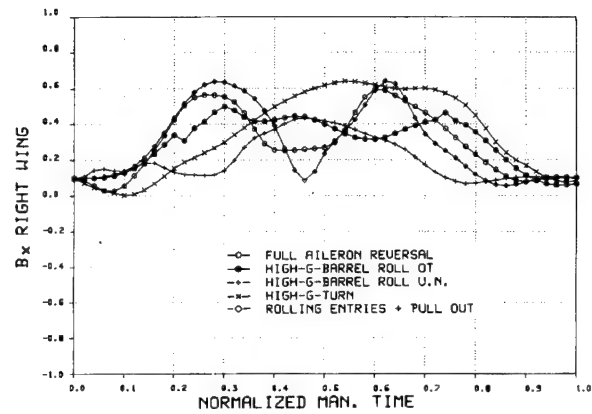
72

Figure 12 — PARAMETERS
EXTREME OPERATIONAL MANEUVERS

Figure 13 — STRUCTURAL LOADS
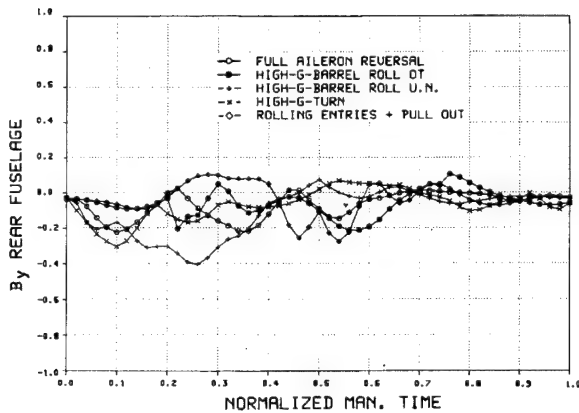EXTREME OPERATIONAL MANEUVERS

Figure 14 — STRUCTURAL LOADS
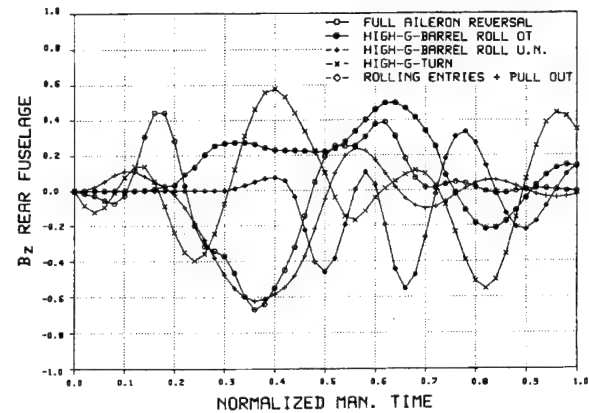EXTREME OPERATIONAL MANEUVERS

Figure 15 — STRUCTURAL LOADS
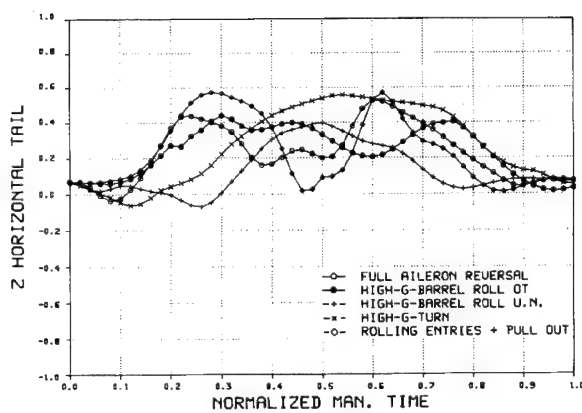EXTREME OPERATIONAL MANEUVERS

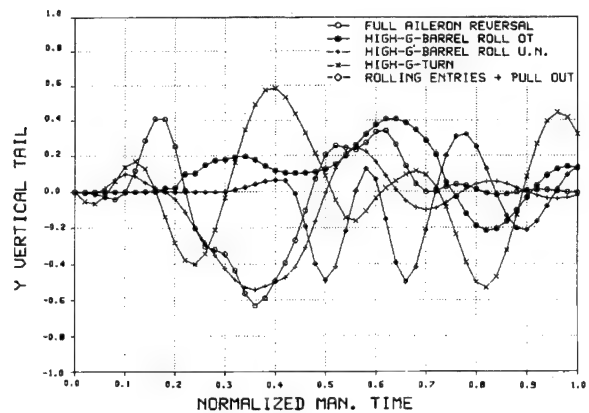Figure 16 — STRUCTURAL LOADS
EXTREME OPERATIONAL MANEUVERS

Figure 17 — STRUCTURAL LOADS
EXTREME OPERATIONAL MANEUVERS

Comparison of extreme operational loads with design loads required by MIL–8861

In the design requirements, several flight conditions are specified, distinguishing between

– symmetrical flight conditions
– pitching maneuvers

– asymmetric flight conditions
– yawing maneuvers
– rolling maneuvers

For these maneuvers, the displacements of the cockpit control are specified. Figure 18 shows in a sketch the longitudinal, lateral, and directional control displacement time histories.

For comparison, the vertical load factor and the structural loads on the main components for all MIL–maneuvers have been calculated. The results are plotted in the same manner as for the operational maneuvers.

In Figure 19, the load factors are presented. At a glance, a moderate variation of the load factor during all maneuvers is evident. Figure 20–24 show the loads on the wing, rear fuselage and the tail planes where the load factors and the loads have been normalized with the design values,
i.e. n_z (design) = 8.0 equaling 1.0

In table 2 the maximum values of the main load parameters, the structural loads for MIL–maneuvers, and the extreme operational maneuvers are presented. The main parameters are absolute values, but the loads have been normalized by the design loads.

This summary shows that in some cases the extreme operational structural loads are lower than the design loads specified by MIL–8861.
The load level is about the same for the symmetrical pitch maneuvers and about, 77% for the unsymmetrical rudder maneuver.

		n_z		n_y	P	β	BxWR	B_yRF	B_zRF	ZHT	YVT
		max.	min.		[°/s]	[°]					
MIL–MANEUVERS	ROLL 180°	0.80	–3.2	0.53	203	3.6	0.22	0.37	0.62	–0.38	0.59
	ROLLING PULL OUT	6.50	+3.9	0.55	124	4.7	0.97	0.31	0.88	0.54	0.77
	ROLL 360°	1.30	–1.1	0.28	210	1.8	0.34	0.39	0.35	–0.18	0.27
	RUDDER KICK	1.10	+0.5	0.83	20	7.5	0.18	0.09	1.00	0.08	1.00
	ABRUPT PITCHING ∧	8.0	+0.8	0	0	0	1.00	1.00	–	1.00	–
	ABRUPT PITCHING ⌢	8.0	+0.9	0	0	0	1.00	0.57	–	1.00	–
OPERATIONAL MANEUVERS	FULL AILERON REVERSAL	6.5	+0.5	0.60	150	5.1	0.81	0.26	0.77	0.53	0.75
	HIGH–G–BARREL ROLL O.T.	5.0	+0.6	0.25	177	2.0	0.60	0.21	0.48	0.44	0.40
	HIGH–G–BARREL ROLL UN.	4.5	+0.7	0.40	164	2.7	0.56	0.40	0.59	0.40	0.52
	HIGH–G–TURN	8.0	+0.3	0.50	132	4.2	1.00	0.37	0.60	0. 70	0.58
	ROLLING ENTRIES+ PULL OUT	6.5	+0.5	0.40	139	1.9	0.81	0.27	0.52	0.57	0.48

Table 2   Maximum values of main load parameters and
            structural loads MIL– Maneuvers / extreme
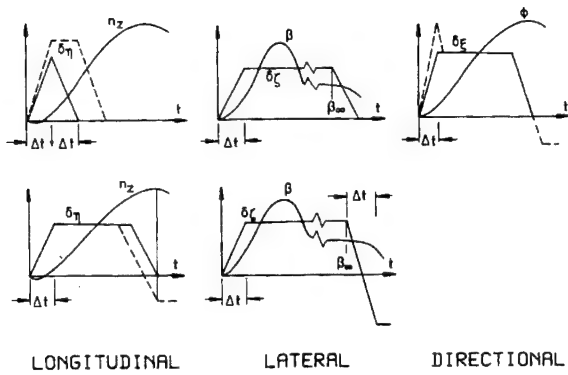   operational maneuvers.

LONGITUDINAL   LATERAL   DIRECTIONAL

Figure 18   COCKPIT CONTROL DISPLACEMENT
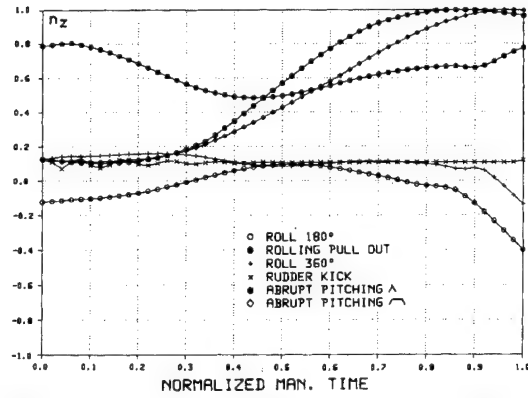MIL–A–008861

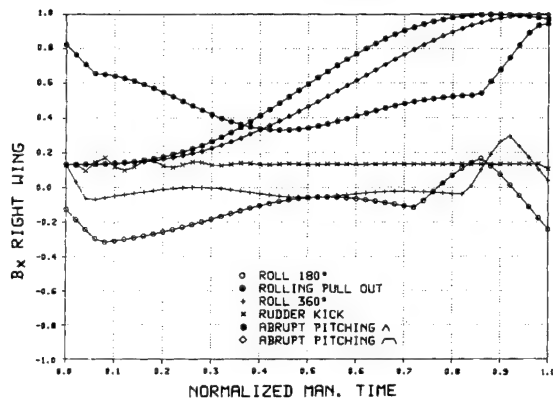Figure 19   LOAD FACTORS–MIL–MANEUVERS

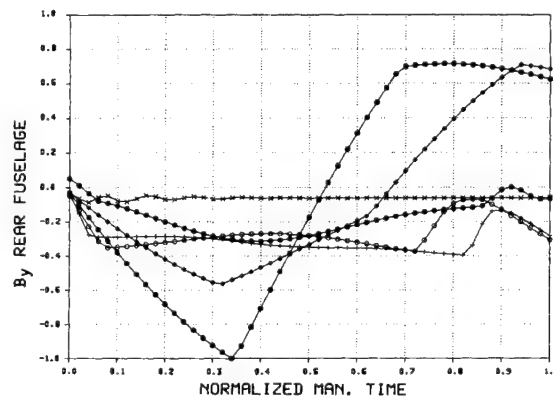Figure 20 STRUCTURAL LOADS MIL–MANEUVERS

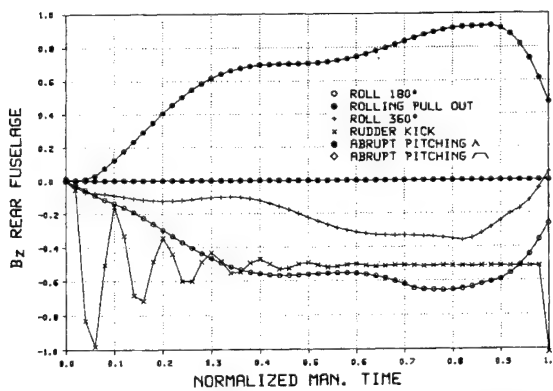Figure 21 STRUCTURAL LOADS MIL–MANEUVERS

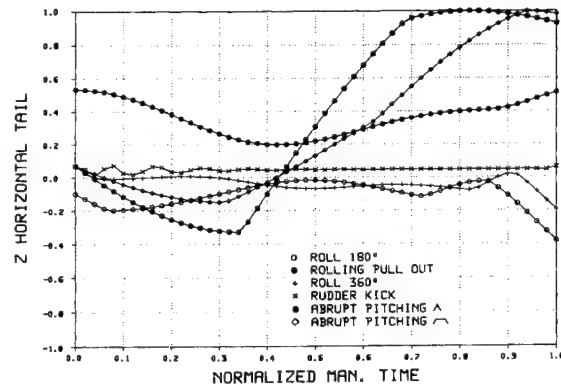Figure 22 STRUCTURAL LOADS MIL–MANEUVERS
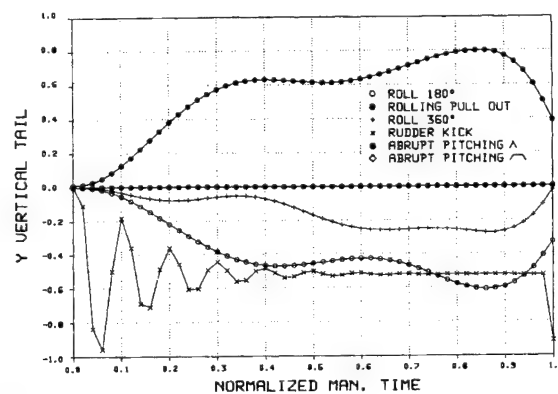

Figure 23 STRUCTURAL LOADS MIL–MANEUVERS

Figure 24 STRUCTURAL LOADS MIL–MANEUVERS

Potential aspects for fatigue design

Fatigue load prediction and monitoring are only as good as the knowledge of the magnitude and the frequency, namely the load parameters expected and monitored in service. The potentiality of the maneuver model allows the realization and the evaluation of long–time measurements of the relevant parameters. The recording should include all fatigue–relevant data, such as mass configuration (weight, C/G, external stores) and the data describing the flight profiles (speed, altitude, flap setting). For standardized maneuvers, the maneuver model provides

- the time history of the main parameters and the loads on the main structural components

- the correlation of the main parameters and the loads.

The spectra of relevant parameters for several operational maneuvers can be determined by systematic measurements made in service. Applying the maneuver model and the parameter spectra, the resultant load spectra for the expected mission of an aircraft can be established. This means the maneuver model can be applied for fatigue load prediction and for fatigue monitoring as well.

Conclusion of Chapter 6.6

For the maneuvers evaluated, a standardization of relevant parameters of motion is feasible, and the results can be made compatible with the equations of motion by tuning and idealization. It could be shown that the standardization is in agreement for the evaluated operational maneuvers flown by a second aircraft type. The parameters of the standardized maneuvers are used in a maneuver model for the determination of the control deflections.

In the maneuver model, the mean values or the extreme values of parameters and the structural loads can be ascertained. For five operational maneuvers, extreme structural loads on main components are presented and discussed. A comparison of the extreme operational loads evaluated with the design loads required by MIL–8861 indicates moderate load sequences but higher load levels for horizontal tail.

7. DISCUSSION

With respect to the specific objectives of WG.27 as defined in Section 4.2:

- **To confirm that information on a number of current operational data was available from service experience of fighter aircraft (CA, US, GE) with particular reference to load relevant parameters (n_z, n_y, p, q, r, ϕ, Θ, Ψ).**

  The following operational data was made available from usage recordings of fighter aircraft from the three NATO participants:

  GE: 3 aircraft types operational
        2 aircraft types by simulation

  US: 1 aircraft type F–16

  CA: 1 aircraft type CF–18

These data were evaluated with respect to load relevant parameters (load factors, rates, altitudes) are complete and applicable for evaluation of the WG.27 approach.

- **To validate these data on operational missions for completeness of parameters and suitability for separating them into mission and maneuvers.**

  The data provided have been checked for completeness and for identification of the maneuver types and found to be satisfactory. In some cases, the recording rates were too low to accurately define the parameter history (e.g. CF–18 control positions, CF–18 roll rate) and in some cases important parameters were missing that would have assisted the process. However, in all cases, the data was sufficient to allow separation into mission and maneuvers for 13 maneuver types.

- **To demonstrate that standardized maneuvers derived from different aircraft data are essentially the same for the same real time maneuver.**

  For the several maneuver types identified, the time histories of the relevant parameters were compared. It was shown that while there was some scatter, and the mean values showed acceptable trends for 5 maneuver types (Pull, Push, Roll, Rolling pull out, Turn) and for the different aircraft types:

  - 5 operational aircraft in service
  - 2 operational by simulation

In the first step, the identification of the maneuvers is done by applying the relevant parameters criteria (load factor, roll rate and bank angle) as specified in the maneuver type description. The start and end time used for determining the maneuver time are identified when the roll rate is zero and the g–level is approximately 1.

For the recordings from service, this approach is not reasonable, because the maneuvers are performed in a rapid and random sequence without returning to the level flight.

For this reason the normalization procedure has been upgraded by introducing of the "peak to peak" normalization procedure that is more realistic for the determination of the maneuver time. This upgraded normalization procedure was used for the second step in the evaluation process to determine Standard Maneuver time histories.

With respect to the limited mandate of WG.27, this analysis was limited to two maneuver types:

  - High–g–turn for all aircraft considered
  - Barrel roll for 4 operational aircraft

For the determination of the Standard Maneuver, the time history of the load relevant parameters has been modulated in a way to cover the most extreme peaks of the control deflections possible. This is done by focusing on the initiation and the completion of the maneuver keeping the response for the maneuver type considered.

This is obtained by idealization of the acceleration time history, in roll(p), pitch(q) and yaw (r). Comparing the Mean Maneuvers and the Standard Maneuvers for the several aircraft types a smaller scatter was demonstrated particularly for the High–g–turn maneuver.

For the final determination of the Standard Maneuver time history, an appropriate introduction of load relevant criteria is recommended. For Example, for a High–g–turn the maximum value of the roll rate (p) is the same for the first and the second peak in a way that the attitude parameters are in compliance with required maneuver.

This has been demonstrated for the Standard Maneuver time history for different aircraft types for the High–g–turn only.

A comparison of the High–g–turn Maneuver was performed which showed that the general Standard Maneuver derived using data from all the aircraft types is representative of the Standard Maneuver time histories for each of the individual aircraft types considered.

- **To determine alternative approaches for data analysis of load relevant parameters, particularly**.

- **Identification of mission maneuver types**

  The identification procedure applied to select the maneuver segments from the operational data base by comparing the recorded data time histories with the defined operational maneuver characteristics have been found to be sufficient.

- **The Analysis of the parameters with respect to**

- **Extreme value distribution for deriving static design loads**
  For this exercise the data base is not sufficient.

- **Mean value distribution for fatigue design.**
  This exercise was initiated using the F–16 data to derive spectra for the main load parameters, taking into account all missions evaluated. The data base is not sufficient, however, for establishing main load parameter spectra for the several maneuver types. For this reason this exercise has been stopped.

- **The correlation of load relevant parameters**
  is ensured in the evaluation procedure by applying a tuning process to ensure a realistic relation between the three Eulerian angles (ϕ, Θ, Ψ) and the angular rates (p, q, r). In general, the modification due to tuning is very small because the data recordings already show a reasonable compatibility. This correlation of the load relevant parameters is the basic prerequisite for the determination of maneuver time histories independent of the quality of the parameters.

- **Perform a limited demonstration study using available CF–18 data and a flight test validated loads calculation process that would compare major section loads calculated using real CF–18 parametric data to those calculated using the parameters generated by a reconstitution of a standardized maneuver as input.**

The verification of the reconstitution process was intended to perform as follows:

A. **for parameter time histories**

(1) the same aircraft type (CF–18) Standard Maneuver reconstituted with CF–18 maneuver data.

(2) another aircraft type (F–16) Standard Maneuver reconstituted with CF–18 maneuver data.

B. **for loads time histories**

(1) the same aircraft type (CF–18) Standard Maneuver reconstituted with CF–18 maneuver data.
(2) another aircraft type (F–16) Standard Maneuver reconstituted with CF–18 maneuver data.

These reconstituted parameter and load time histories have been compared with a specific High–g–turn maneuver selected from CF–18 usage data.

A: The comparison of the reconstituted parameters for the same aircraft types. (1) as plotted in 6.3.1.3 shows good agreement for the loads relevant parameters (roll and pitch), with particular agreement on the peaks. The exception is the lack of agreement for the yaw in the initiation phase which is explained by a start value different from zero.
The comparison of the reconstituted parameters for another aircraft type (2) as plotted in 6.3.1.4–A shows a similar time history but there is a shift of the peaks at initiation and an ever larger shift at the completion of the maneuver. The initial approach for the determination of the time factor only considered the start and the end of the maneuver. To overcome the above anomaly, a second step which adds consideration of the peaks for the initiation and completion of the maneuver has been added. The results are plotted in 6.3.1.4–B. With this improvement of the time reconstitution the comparison shows also an acceptable agreement in the maneuver time histories as for the same aircraft type (1). That means the Standard Maneuver of another aircraft is applicable applying the reconstitution factors of the aircraft to be considered.

B: The loads have been determined as section loads for the major components:

– Fuselage bending, forward and aft

– Wing bending

– Taileron shear

The calculation of the loads have been performed using the BI/CDSD Loads Calculation methodology (described in 6.4.1) for the reconstituted parameters and for the actual measured parameters. Due to demonstrated good agreement between the reconstituted parameters for the same aircraft type (CF–18) (A (1)) and those from actual measured parameters, good agreement was also expected for the load time histories. (Chapter 6.3.1.1–6.3.1.3). Therefore the verification of the loads process for the same aircraft type (B (1)) has not been pursued under the WG.27 activity.
With respect to the close time schedule and the amount of data work the next step has been performed i.e. the verification of the loads for another aircraft (B (2)).

In general, as described in Chapter 6.4.2, there is very good agreement for the peak and valley predictions. This means that the reconstituted loads histories are sufficiently accurate for use in static and fatigue assessments. There were some discrepancies noted in the time correlations between real and reconstituted maneuvers. This is an important issue since the full balance of the aircraft relies on coincident predictions. This issue was investigated and determined to be the result of the maneuver start–stop definition used during the formation of the non–dimensionalized data.

The issue is well understood and the methodology has been corrected. There was not however, sufficient time to recalculate the loads using the corrected data.

This exercise was limited to one maneuver and therefore only provides an indication of the performance of the technique. More maneuvers, both symmetrical and asymmetrical, must be studied.. The effect of abruptness must also be addressed before the observation that the reconstituted loads histories are sufficiently accurate for static and fatigue purposes can be fully accepted. Unfortunately, this was beyond the scope of the WG.27 mandate.

- **Application of a maneuver model**

  The maneuver model has been applied for the determination of the extreme operational loads on the GAF–F–4F aircraft (Chapter 6.6) for comparison with design loads required by MIL–8861.

  In this process it was been demonstrated that the control deflections determined in the maneuver model match with the time histories of the parameters to be obtained. That means the control deflections necessary to perform the maneuver can be determined in the maneuver model

  Time did not permit the application and verification of a maneuver model. Also, essential inputs to the Maneuver Model are the control system data and the global aerodynamic data for the aircraft being studied. This data could not be released by Canada under this program.

  Although the validation exercise could not be pursued, the maneuver model has been developed and can be applied if the data were available.

8. CONCLUSION

8.1. Availability and applicability of operational data

For the evaluation of the operational parameters, the following data were made available and have been judged as applicable.

a) Flight test data by GAF Test Centre
   for specific operational maneuvers on three aircraft
   (Alpha Jet, F–4F, MRCA)

b) Data from simulations by GAF
   for specific operational maneuvers
   recorded on Dual Flight Simulator for two aircraft
   (F–4, JF–90)

c) Service data by USAF recorded on the F–16
   (selected subset from over 300 sorties from 97 aircraft)

d) Service data by CF recorded on the CF–18
   (selected subset of CF–18 fleet monitoring)

Taking all data available, which have been found to be suitable for separation into maneuver types, the data base is about 13 maneuver types. For two maneuver types, High–g–turn and Barrel roll, more than 60 maneuvers for each maneuver type have been considered as applicable for evaluation.

All data made available have been judged as sufficiently, complete and applicable for evaluation in the frame of the WG.27 mandate.

8.2 Verification of normalized maneuver parameter time histories and determination of Standard Maneuvers

The normalization procedure has been developed and applied to the data base for 3 GAF–aircraft in operation and one aircraft in development covering:
        8 maneuver types derived from
        flight test
        4 maneuver types derived from
        simulations.

The normalization has been done for the F–4 aircraft flight test data as well as for the F–4 aircraft data obtained by simulation. Comparing the time histories, the scatter band is marginally different, therefore the simulation data can be considered as equivalent to those derived from flight test. The conclusion drawn is that simulation data may have the potential to replace flight recordings.

For service data from the USAF for F–16 aircraft and from the CF for CF–18 aircraft, an identification of the maneuver types from the recordings was completed without any problems. These identified maneuvers have been normalized for forming mean values for:
        6 maneuver types for F–16
        7 maneuver types for CF–18.
The comparison of the normalized maneuvers for the several aircraft types has been done using mean values. The scatter band is about the same as that for the individual aircraft. This means that the normalized time histories can be considered as independent of the aircraft type.

For the WG.27 study, the determination of Standard Maneuver time histories has been limited to two maneuver types:

- for each aircraft type separately
- for all aircraft types considered (5 aircraft)

The maneuver types chosen are the High–g–turn and the Barrel roll because of the sufficient data base i. e. includes all aircraft and has the biggest number of maneuvers.

For the definition of Standard Maneuver independent of aircraft type, an idealization of the maneuver time history combined with load relevant criteria was performed.

Comparing the Standard Maneuver parameter time histories for the several aircraft types, the course and the relation of the parameters are the same and the scatter of the values is acceptable within the scope applying an envelope covering the load relevant criteria.

That means the Standard Maneuver independent of the aircraft type is applicable as unit input for calculation of the movement of a specific aircraft by reconstitution of the real aircraft configuration and flight condition.

The actively controlled aircraft (MRCA, F–16, CF–18) fit in the same scatter band as the conventional controlled aircraft. This means the hypothesis that the operational maneuvers are performed in the same way, i. e. performing the same normalized parameter time history, can be considered as confirmed.

8.3 Comparison of Standard Maneuver time histories and the corresponding loads with flight test validated loads

This exercise was limited to one maneuver type as a feasibility study. The High–g–turn maneuver was selected for the demonstration of the reconstitution of the Standard Maneuver time histories and the loads process.

The reconstituted parameters have been compared with a specific High–g–turn maneuver selected from CF–18 usage data. The comparison has been performed for the Standard Maneuver time histories

- for the same aircraft type (CF–18)
- for another aircraft type (F–16)

A minor improvement (peak to peak adjustment) of the time reconstitution the comparison for another aircraft shows an acceptable agreement in the maneuver time histories for both aircraft. An application of the Standard Maneuver independent of the aircraft type would have given better agreement, but this had not been determined at this time. This means the Standard Maneuver independent of the aircraft type is representative of the time histories of several aircraft in an idealized form and can be reconstituted using the reconstitution factors of the aircraft to be considered.

It is concluded that Standard Maneuvers, determined by evaluation of several aircraft types based on a sufficient number of maneuvers, can be considered as representative.

The calculation of the loads has been performed using the BI/CDSD Loads Calculation Methodology for the reconstituted parameters and for the actual measured parameters. The BI/CDSD methods had been validated against flight test data. Due to demonstrated good agreement between the reconstituted parameters for the same aircraft type and those from actual measured parameters no further verification of the loads process was done by WG.27.

The loads have been calculated for the reconstitution based on the F–16 Standard Maneuver. In general there is a good agreement for load peaks and valleys.

This implies that operational load histories derived from Standard Maneuvers will be sufficiently accurate for use in static and fatigue assessment.

Note that in this feasibility study, the control deflections applied have been taken from the selected maneuver from the CF–18 usage data. This means that any load variation is only due to the variation in the parameters of aircraft movement from the reconstitution process and not from the loads process.

Time did not permit the application and verification of the maneuver model in this feasibility study. Although the validation exercise could not be pursued the maneuver model has been developed and could have been applied if the control system data for the CF–18 were available.

8.4 Application and verification of the Maneuver Model

The maneuver model has been applied for the determination of the extreme operational loads on the GAF F–4F aircraft for comparison with design loads required by MIL–8861.

In this exercise the boundary conditions have been determined by applying the extreme maximum values of the corresponding

maneuvers in the frame of this evaluation or by scaling up the values to the load factors required by MIL–8861.

In this study it has been demonstrated that the control deflections determined in the maneuver model match with the time histories of the parameters to be obtained. This means the control deflections necessary to perform the maneuver can be determined using the maneuver model.

For verification of the control deflections due to the specific control laws , particularly for aircraft activating more than one control surface for controlling the aircraft around one axis, e. g. ailerons and tailerons for rolling, the control gains or the control laws have to be taken into consideration in the maneuver model. Unfortunately this essential data could not be made available in the time schedule of the WG.27 mandate.

THE CONCLUSIONS FROM THE WG.27 ACTIVITIES ARE AS FOLLOWS:

- The usage data made available have been judged as complete for application and sufficient for the evaluation intended.

- The normalization of all maneuver parameter time histories leads to the same course and relation of the parameters for the same maneuver type independent of the aircraft type and the control system, which has been verified by comparing the mean maneuver time histories for several aircraft, both operational and simulated.

- The determination of Standard Maneuvers independent of aircraft type has been demonstrated for two maneuver types by idealization of the maneuver time history taking into account load relevant parameters, as basic maneuvers for the calculation of loads, for use in static design and for fatigue assessment, applying the corresponding boundary conditions.

9. RECOMMENDATIONS

9.1. The initial evaluation of the concept done by WG.27 has demonstrated the feasibility of determining loads from operational flight maneuvers. Further work is necessary to expand the scope of the WG.27 investigation and to confirm the WG.27 conclusion.

9.2. To cover more operational maneuvers in several NATO nations in the whole evaluation procedure and to extend the number of Standard Maneuvers in the reference database, the following activities are recommended:

- Establishment of a list of operational maneuvers in usage for NATO nations

- Obtain more operational maneuver recordings from service especially from European nations

- Identify and verify more Standard Maneuvers

- Establish of spectra and extreme value distributions of relevant maneuver parameters (n_z, n_y, p, q, r, Φ) separated for maneuver types in order to determine boundary conditions

- Apply and verify the Maneuver Model including calculation of control deflections and loads on major structural components.

9.3. WG.27, having fulfilled its mandate, should be terminated.

10. REFERENCES

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   Analysis and Prediction of Structural Loads on Combat Aircraft due to Operational Manoeuvres

   (1) Nr. T/RF43/A0013/A1413 by H. Balke, Mai 1982
   (2) Nr. T/RF43/C0051/C1451 by H. Balke, August 1984
   (3) Nr. T/RF43/D0036/D1436 by H. Balke, J. Molkenthin and V. Ladda November 1987

2. AGARD Conference Proceedings No. 375 "Operational Loads Data"

   Page 13: **Evaluation of Operational Loads to verify Structural Design** by H. Struck, April 1984

3. AGARD Report No. 730 **Combat Loads on Modern Fighters**

   by   R. Mohrman, February 1986
         G. Schmidinger
         H. Struck

4. AGARD Report No. 746 **Workshop on Design Loads for Advanced Fighters**, April 1987

5. Presentation at 69. AGARD – SMP Meeting by C. A. Babish and J. M. Slye

   Study of F–16 Maneuvers of Wright–Patterson AFB arranged by C.L. Petrin

6. AGARD Conference Proceedings 506 "Fatigue Manage ment"
   Ref.: 7: **A Parametric Approach to Spectrum Development** by D.L. Simpson, R. J. Hiscocks and D. Zavitz, May 1991

7. Presentation at 75. AGARD – SMP Meeting by M. B. Zgela National Defence Headquarters, Canada **CF–18 Loads Development Activities in the Canadian Forces**

11. AIRCRAFT TYPE DESCRIPTION*

JF–90 :   **Air Combat Fighter**
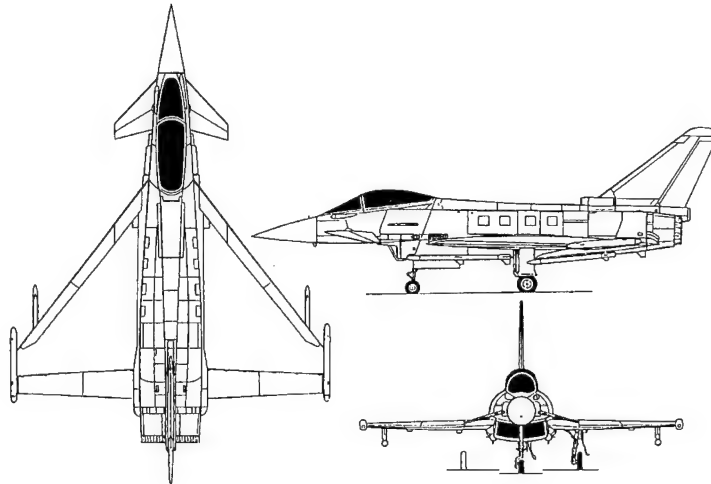
F–4F :   **Interceptor and Tactical Strike Fighter**
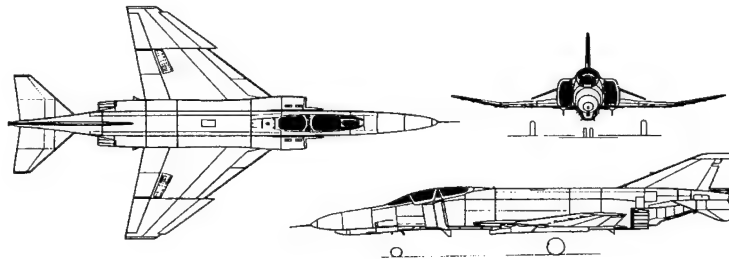
MRCA :   **Multi Role Combat Aircraft**
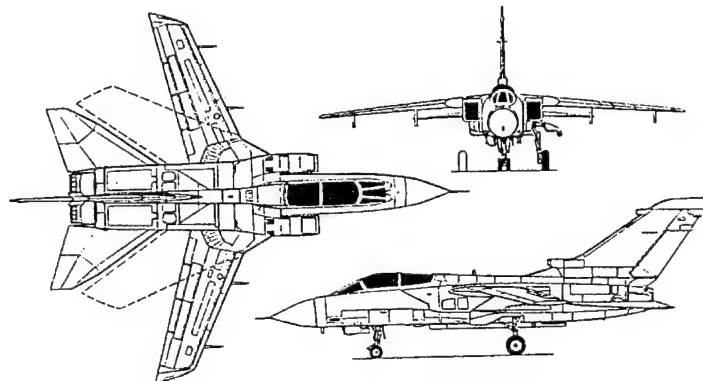
Alpha–Jet :   **Advanced Trainer and Light Tactical Fighter**

82
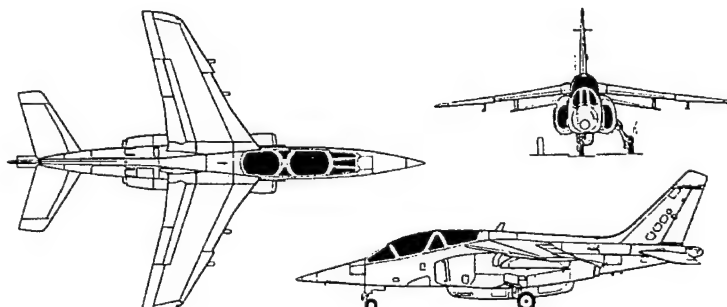
F–16   :   Air Combat
                 Fighter
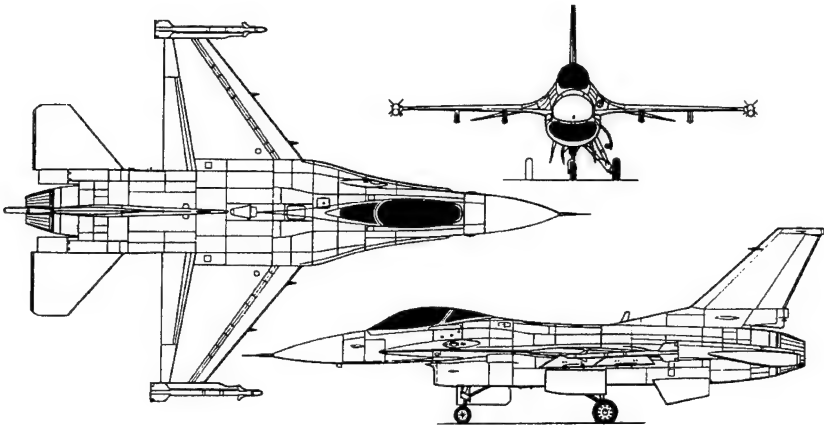
CF–18 :   Air Combat
                 Fighter
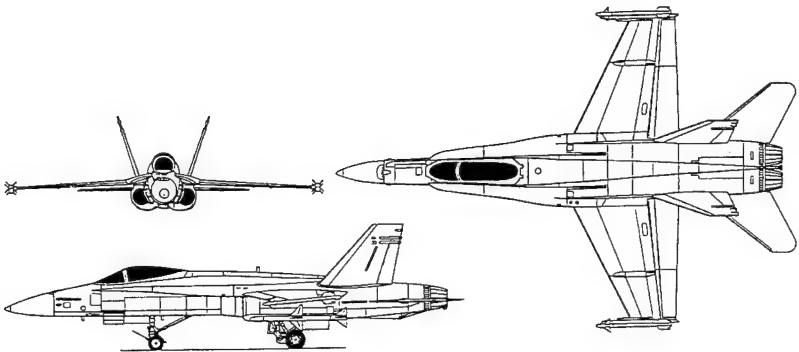
Aircraft–Specifications   *   Drawings not to scale

Aircraft–Type	Length [m]	Span [m]	Wing area [m^2]	MTOW [kg]	Max speed [Ma]
Alpha–Jet	11.30	9.10	17.50	7,940	0.9
F–4F	19.20	11.70	49.20	27,500	2.2
MRCA	16.70	8.60 / 13.90	25.00 / 30.00	28,000	2.2
JF–90	15.96	10.95	50.00	21,000	2.0
F–16	15.10	9.50	27.90	17,010	2.0+
CF–18	17.10	12.30	37.20	25,400	1.8+

ANNEX A

Plot Comparison of Normalized Time Histories

6.1.3.3.1 GAF – F–4F High g turn

6.1.3.3 GAF – Normalized Time Histories
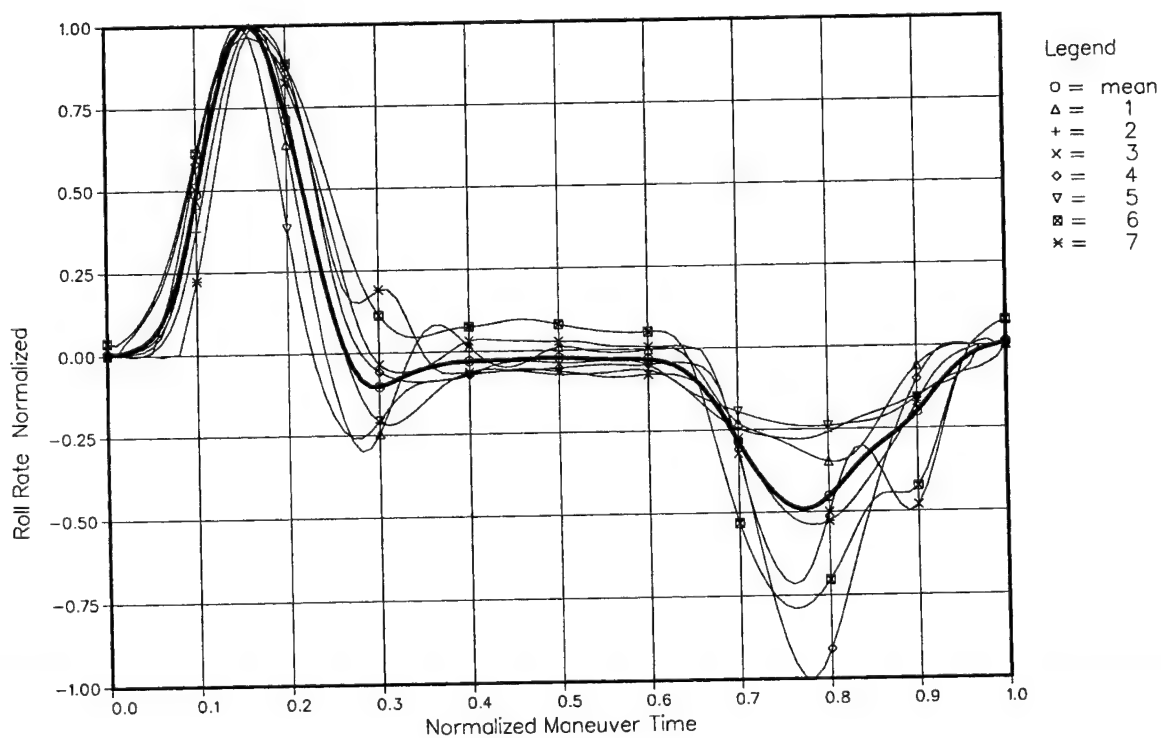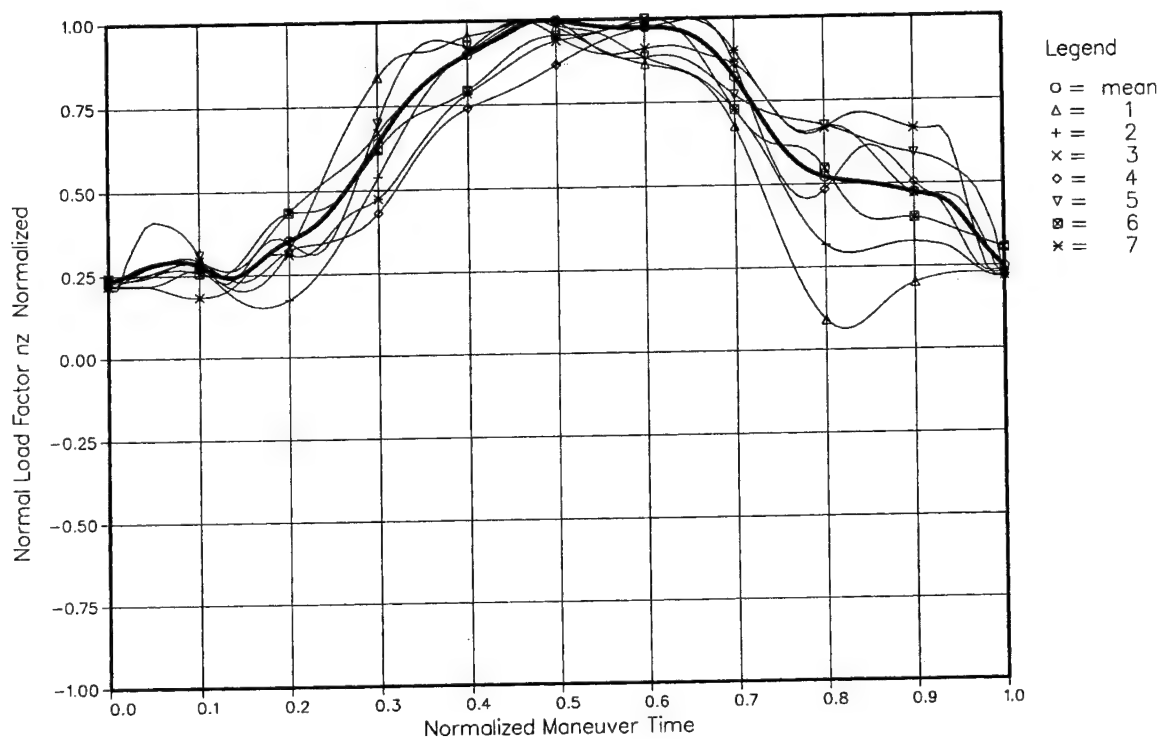
6.1.3.3 GAF – Normalized Time Histories

6.1.3.3.1 GAF – F–4F High g turn
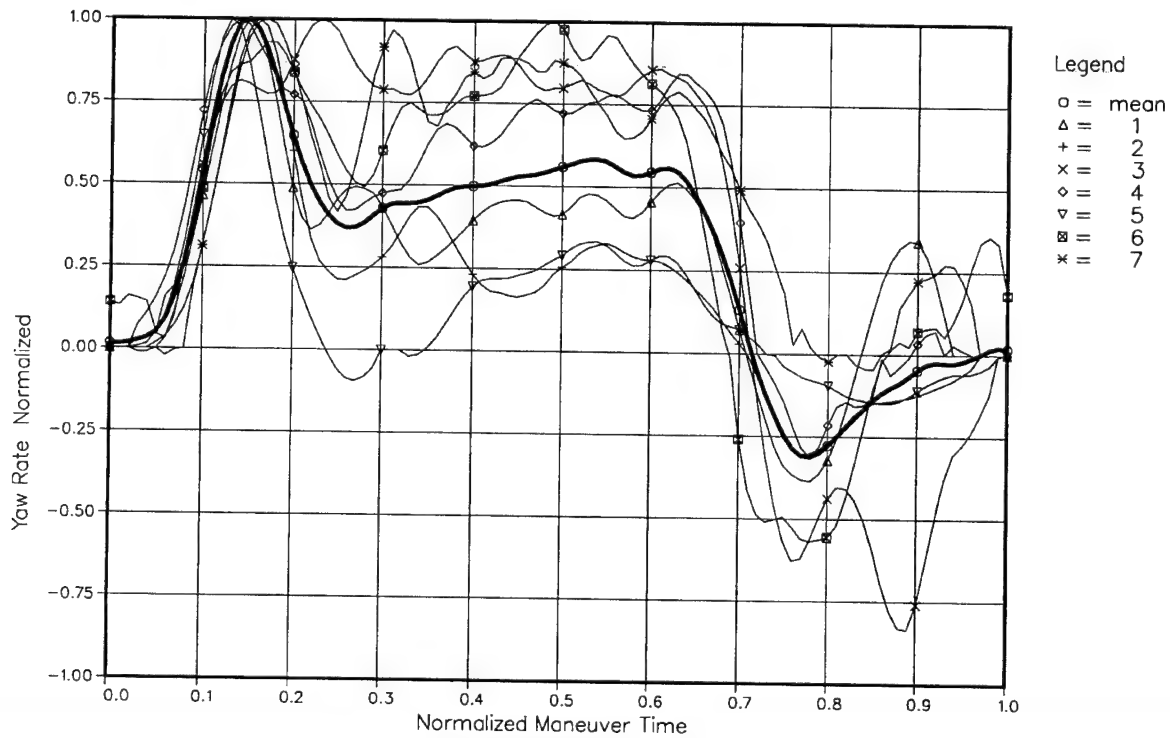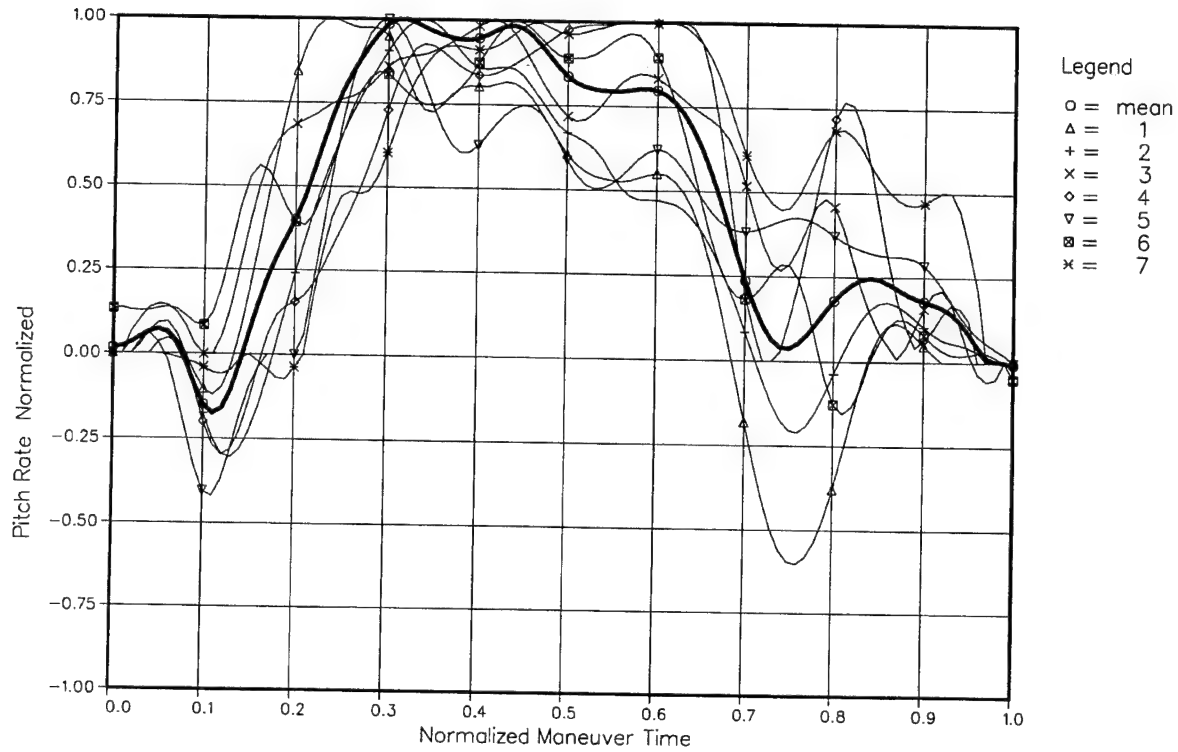
6.1.3.3 GAF – Normalized Time Histories

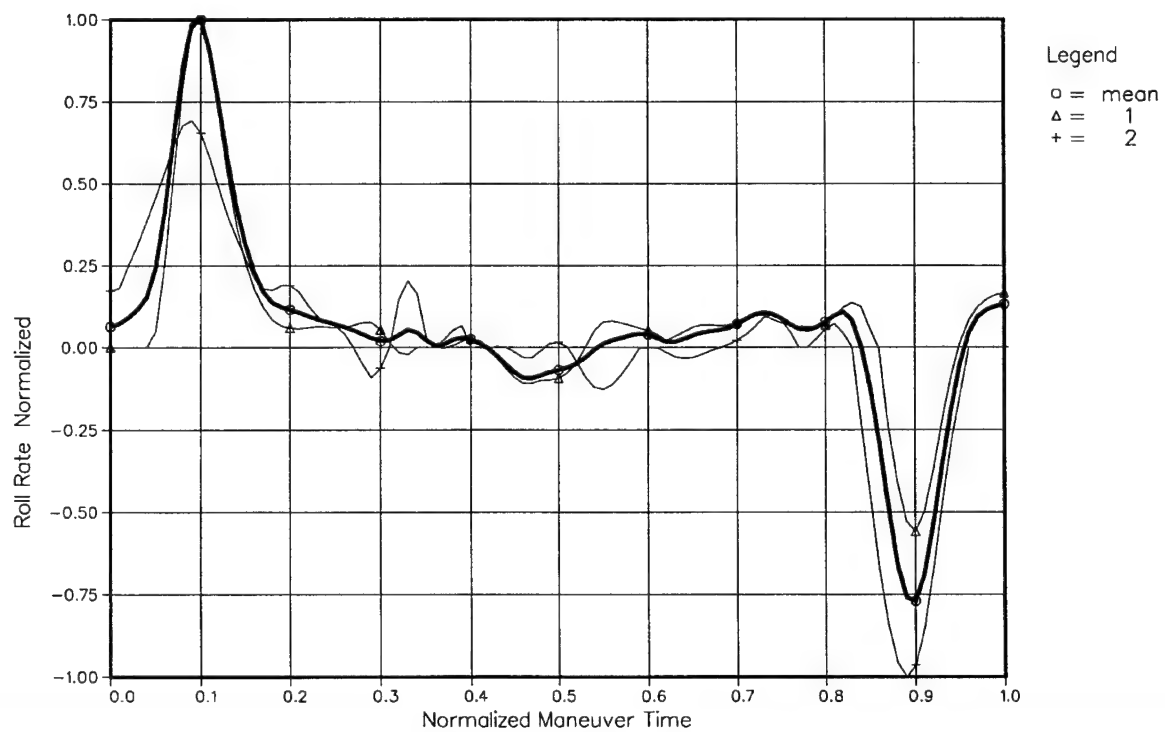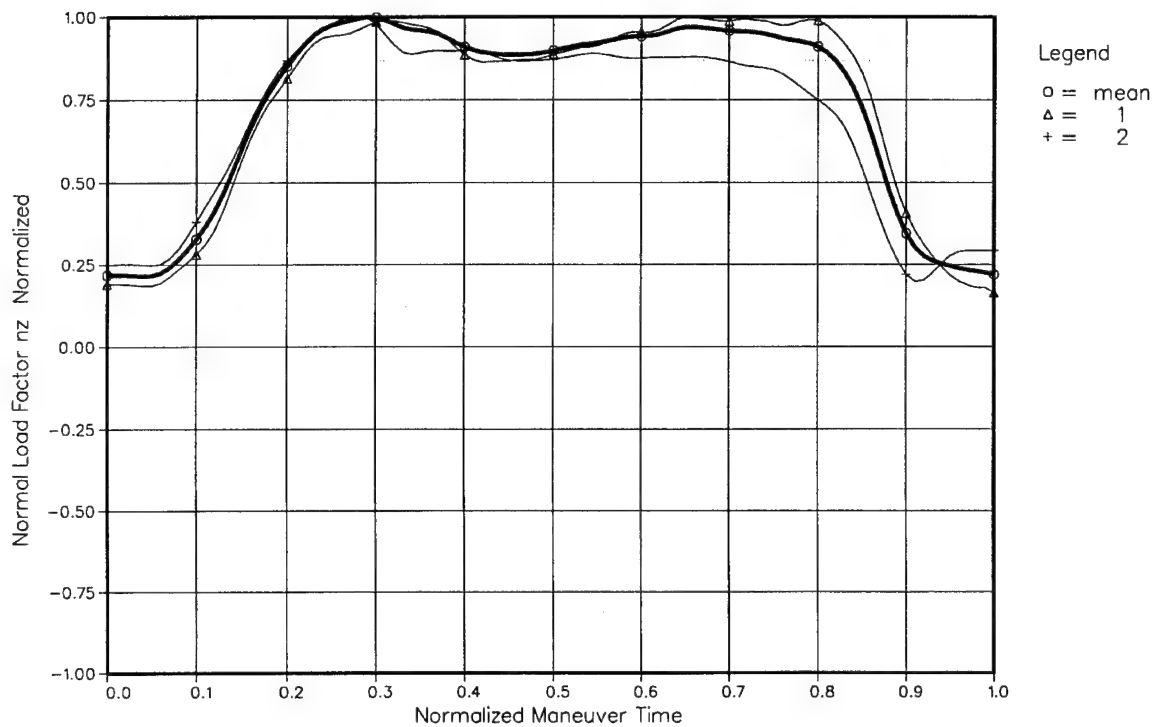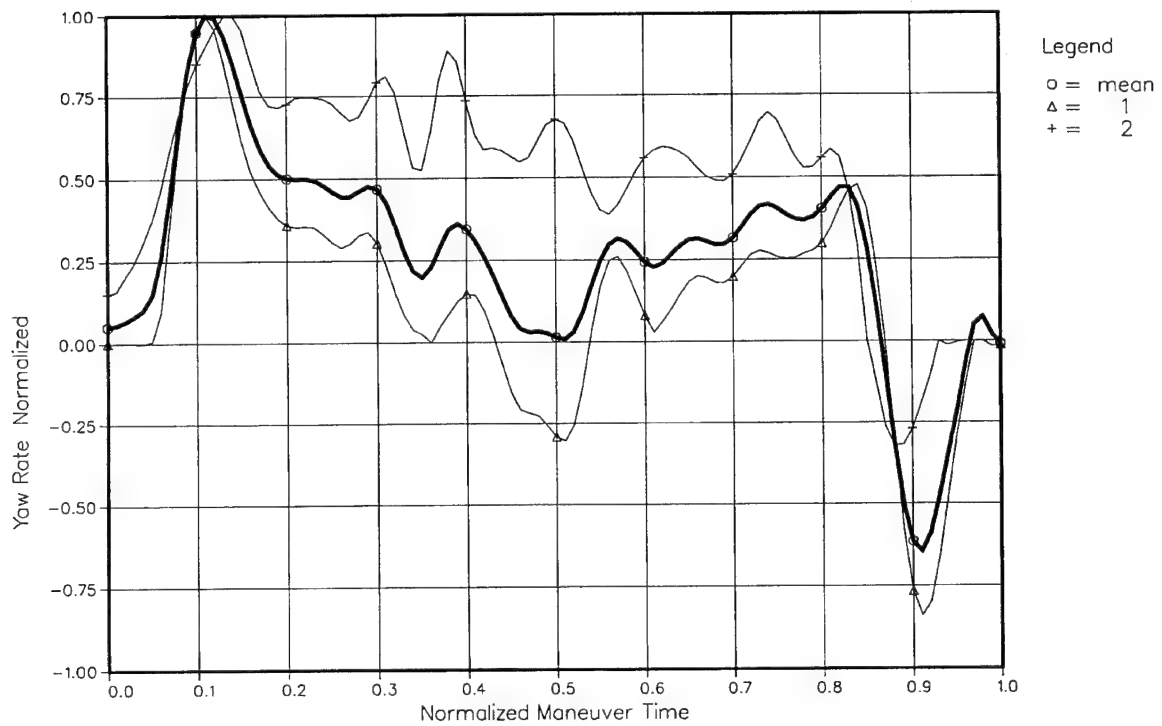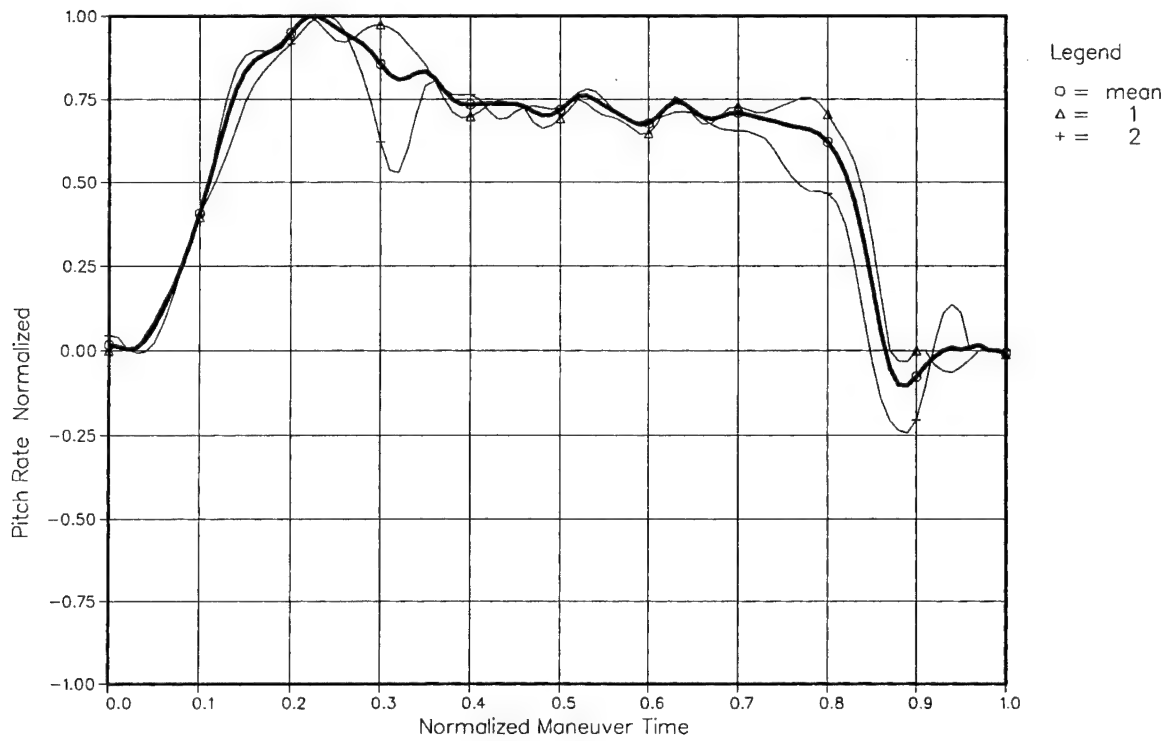### 6.1.3.3.1 GAF – F–4F High g turn

Maneuver Time (sec)	Normal Load Factor n_z (–)	Roll Rate (deg/sec)	Pitch Rate (deg/sec)	Yaw Rate (deg/sec)	Δ Bank Angle (deg)	Maneuver Identification Number
8.100	4.392	118.31	18.887	5.213	87.578	1
7.500	4.635	126.23	22.084	7.002	84.939	2
8.800	4.580	75.84	11.743	3.008	88.333	3
8.100	4.292	77.47	9.957	3.500	86.708	4
7.800	4.770	155.16	16.146	7.110	88.962	5
7.000	5.042	69.31	10.830	2.899	75.495	6
9.400	4.547	75.36	9.501	2.873	86.037	7
8.1	4.61	99.669	14.164	4.515	85.436	mean

Recorded extreme values

6.1.3.3 GAF – Normalized Time Histories

6.1.3.3.2 GAF – Alpha–Jet High g turn
   Maneuver Comparison

.1.3.3 GAF – Normalized Time Histories .

6.1.3.3.2 GAF – Alpha–Jet High g turn
  Maneuver Comparison

Legend

o = mean
Δ = 1
+ = 2
× = 3
◇ = 4

Legend

o = mean
Δ = 1
+ = 2
× = 3
◇ = 4

6.1.3.3 GAF – Normalized Time Histories

6.1.3.3.2 GAF – Alpha–Jet High g turn
           Maneuver Comparison

Maneuver Time (sec)	Normal Load Factor n_z (–)	Roll Rate (deg/sec)	Pitch Rate (deg/sec)	Yaw Rate (deg/sec)	Δ Bank Angle (deg)	Maneuver Identification Number
21.00	4.889	96.50	12.172	3.429	84.373	1
20.00	5.038	87.77	13.367	4.446	86.793	2
25.00	4.301	37.19	9.012	2.388	83.010	3
28.00	4.745	53.68	13.206	2.578	82.878	4
23.50	4.743	68.785	11.939	3.210	84.264	mean

Recorded extreme values

6.1.3.3 GAF – Normalized Time Histories

6.1.3.3.3 GAF – MRCA High g turn
Maneuver Comparison

Legend
o = mean
Δ = 1
+ = 2

Legend
o = mean
Δ = 1
+ = 2

6.1.3.3 GAF – Normalized Time Histories .

6.1.3.3.3 GAF – MRCA High g turn
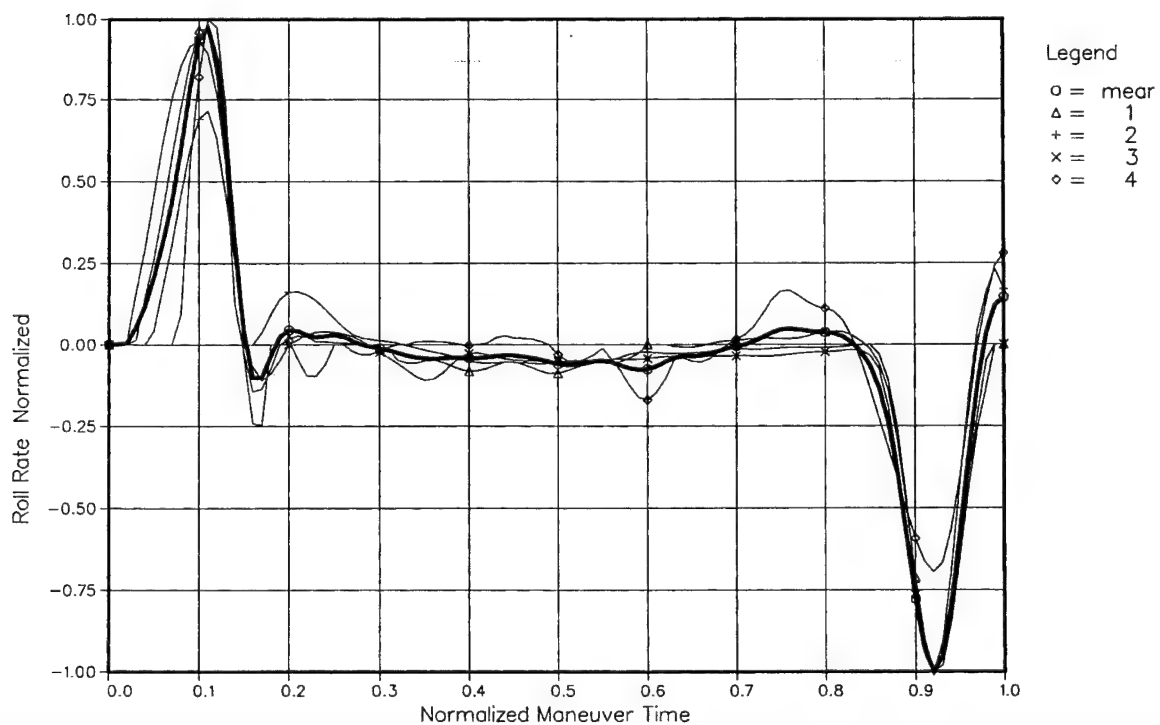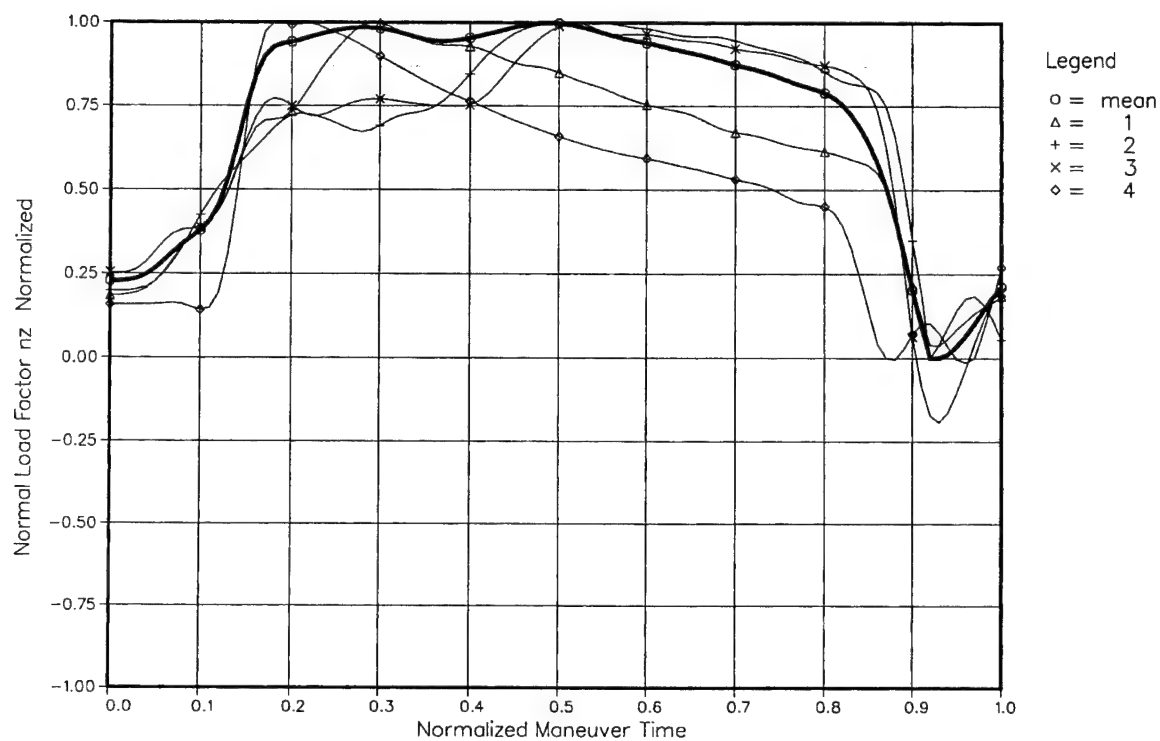**Maneuver Comparison**

6.1.3.3 GAF – Normalized Time Histories

6.1.3.3.3 GAF – MRCA High g turn
       Maneuver Comparison

Legend

o = mean
Δ = 1
+ = 2

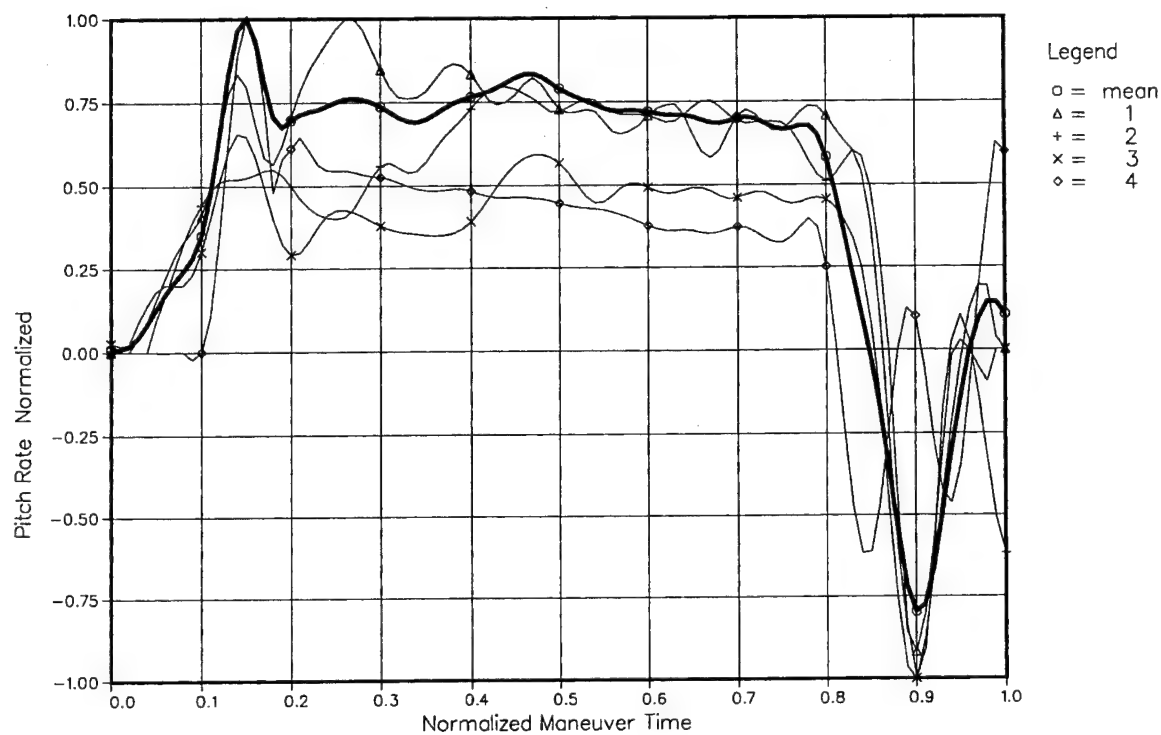| Maneuver Time (sec)	Normal Load Factor n_z (–)	Roll Rate (deg/sec)	Pitch Rate (deg/sec)	Yaw Rate (deg/sec)	Δ Bank Angle (deg)	Maneuver Identification Number
24.00	5.432	95.33	14.42	7.343	91.333	1
23.00	3.458	38.01	8.81	3.491	77.124	2
23.50	4.445	66.67	11.62	5.417	84.229	mean

Recorded extreme values

6.1.3.3 GAF – Normalized Time Histories

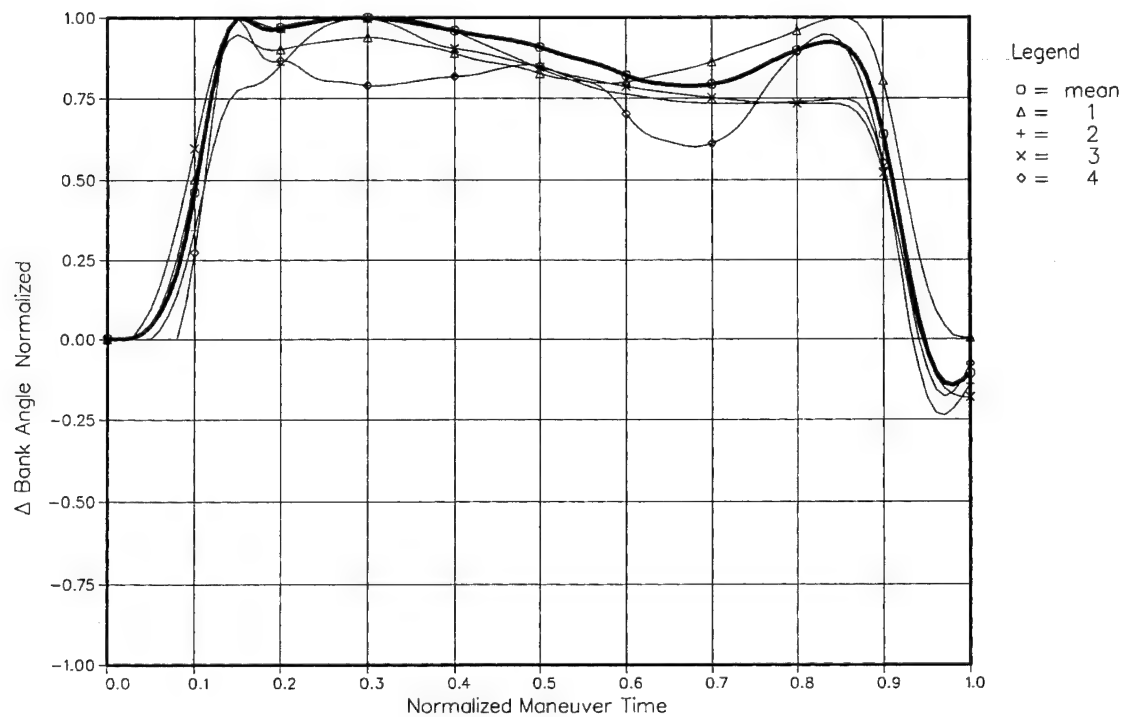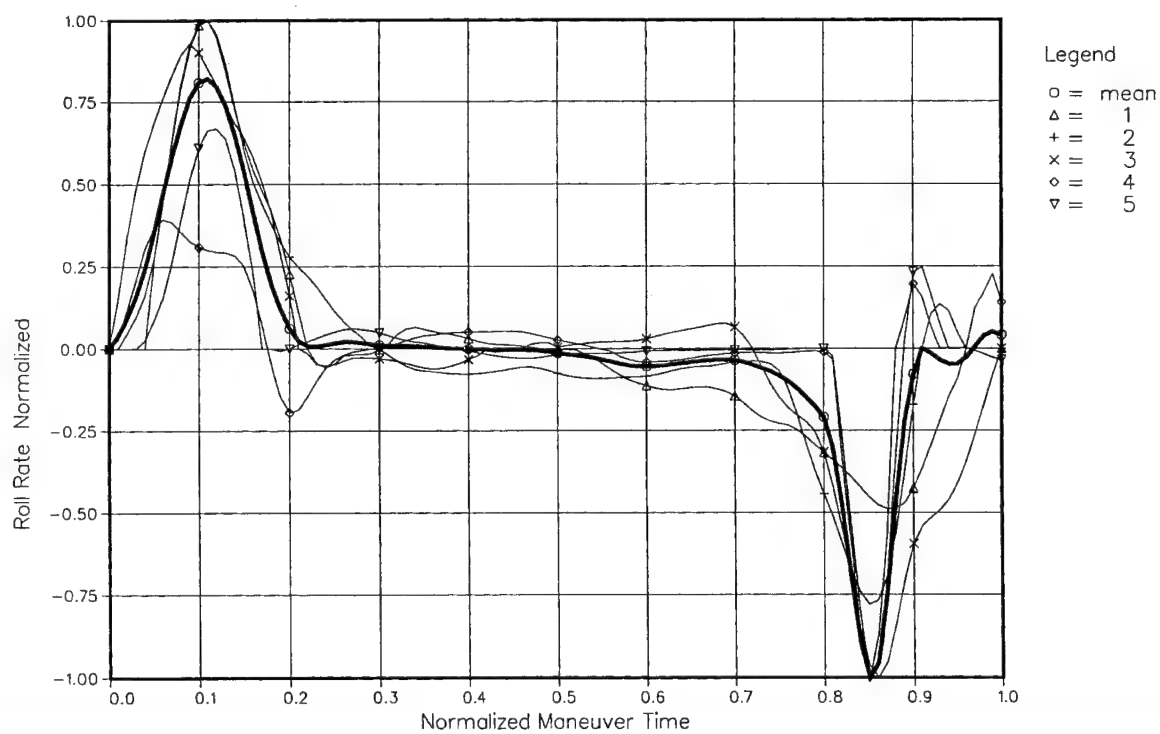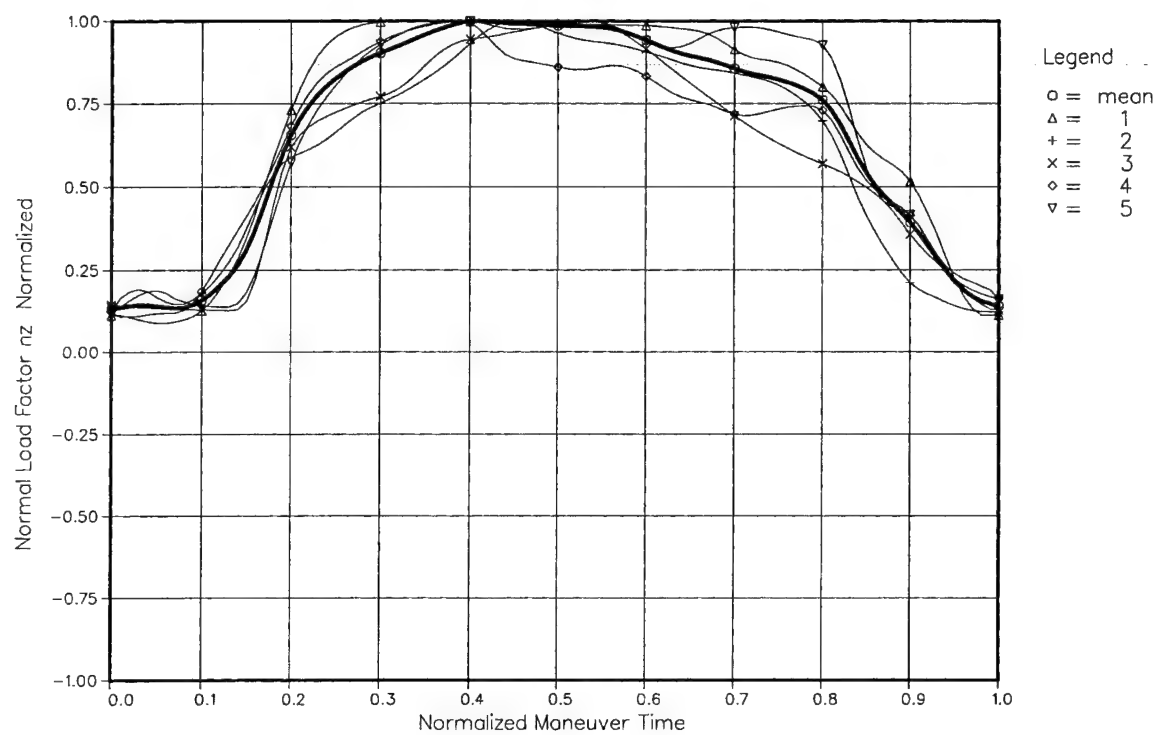## 6.1.3.3.4 GAF – F–4F Simulation High g turn
Maneuver Comparison

Legend
o = mean
Δ = 1
+ = 2
× = 3
◇ = 4

Legend
o = mean
Δ = 1
+ = 2
× = 3
◇ = 4

6.1.3.3 GAF – Normalized Time Histories

6.1.3.3.4 GAF – F–4F Simulation High g turn
Maneuver Comparison

6.1.3.3 GAF – Normalized Time Histories

6.1.3.3.4 GAF – F–4F Simulation High g turn
Maneuver Comparison

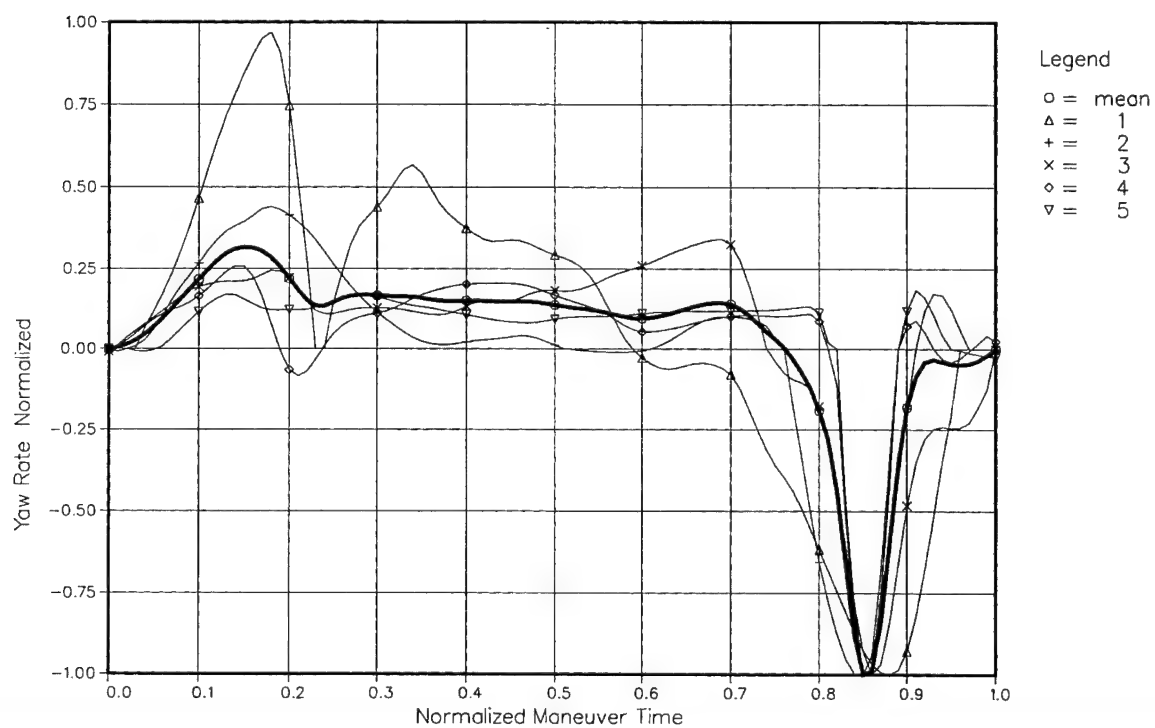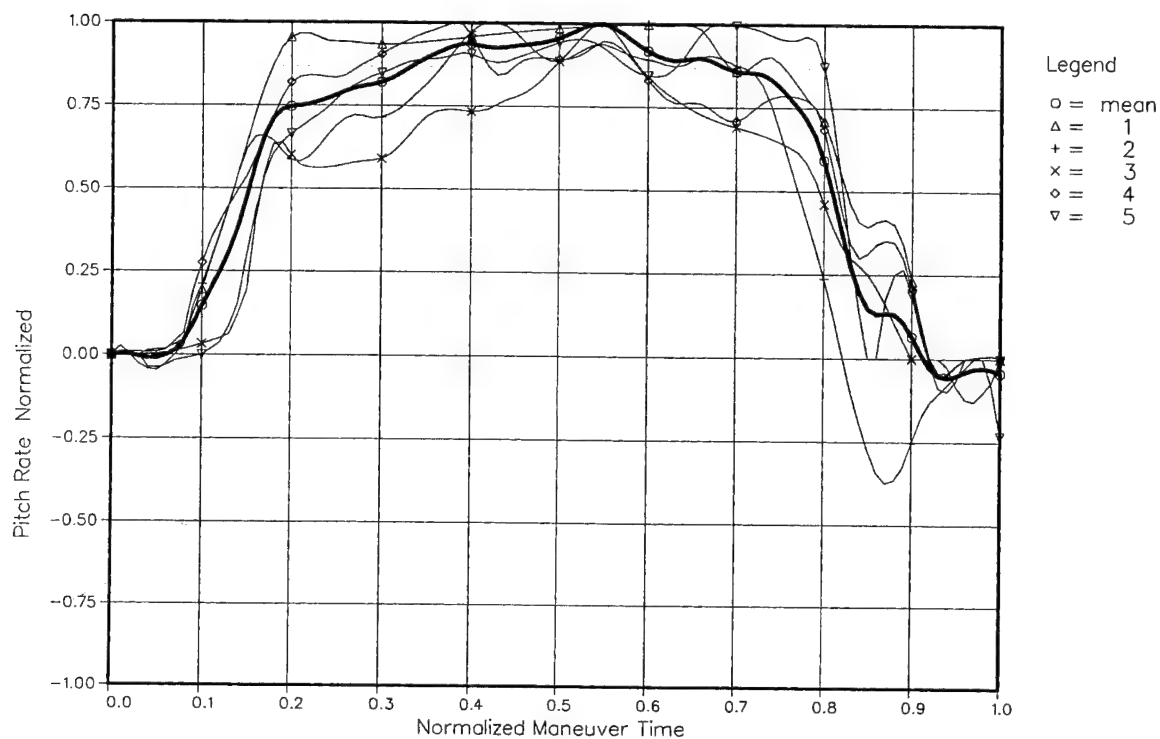| Maneuver Time (sec)	Normal Load Factor n_z (–)	Roll Rate (deg/sec)	Pitch Rate (deg/sec)	Yaw Rate (deg/sec)	Δ Bank Angle (deg)	Maneuver Identification Number
19.76	5.479	66.63	14.622	5.123	86.485	1
19.16	5.051	92.19	19.657	10.556	86.334	2
16.12	5.100	81.07	24.508	6.491	92.159	3
23.20	6.710	105.83	30.239	9.809	91.562	4
19.56	5.585	86.43	22.257	8.00	89.135	mean

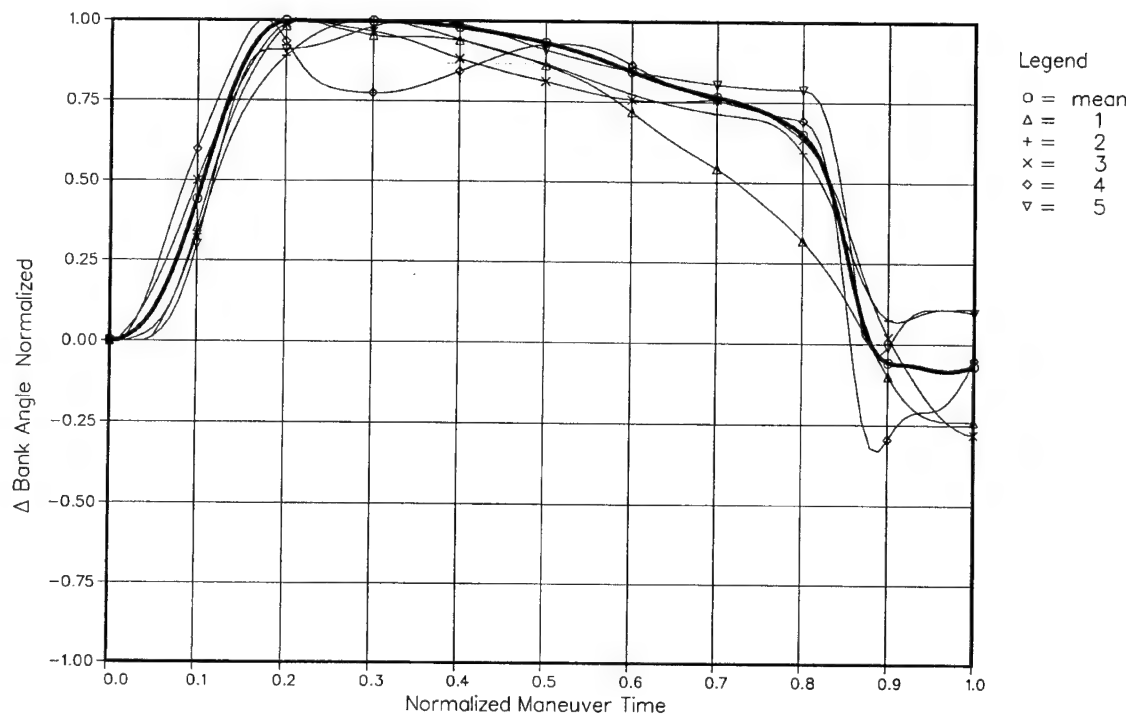Recorded extreme values

6.1.3.3 GAF – Normalized Time Histories

6.1.3.3.5 GAF – JF–90 Simulation High g turn
Maneuver Comparison

6.1.3.3 GAF – Normalized Time Histories

6.1.3.3.5 GAF – JF–90 Simulation High g turn
            Maneuver Comparison

6.1.3.3 GAF – Normalized Time Histories

6.1.3.3.5 GAF – JF–90 Simulation High g turn
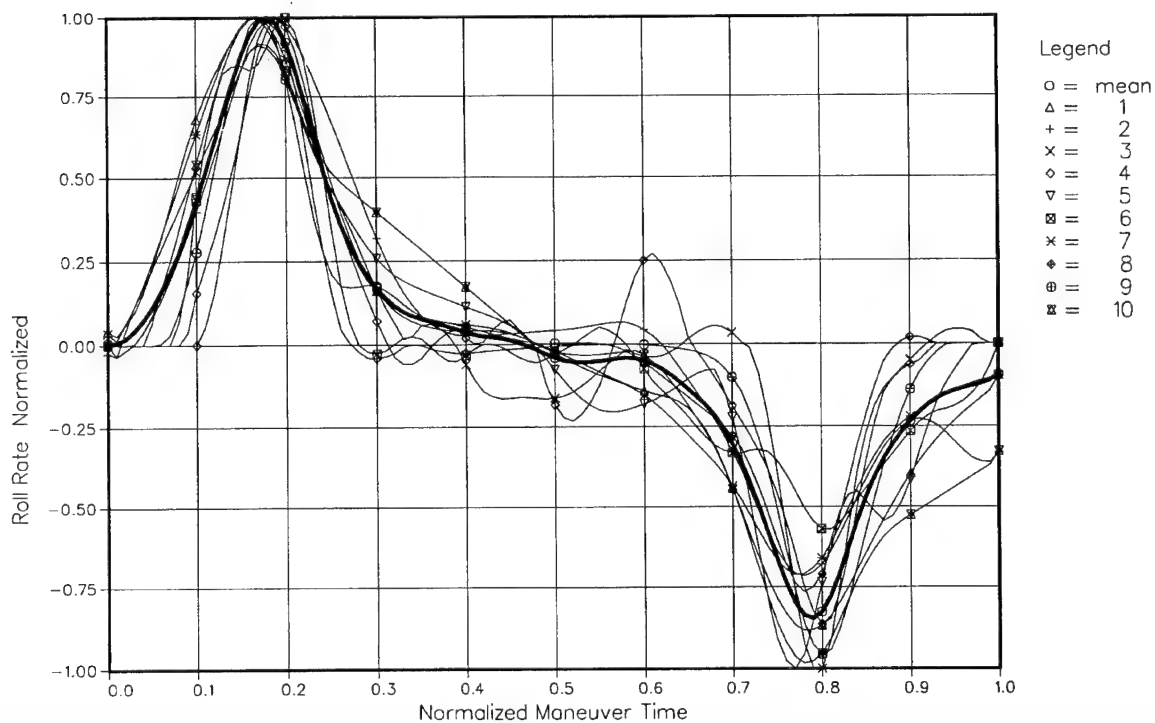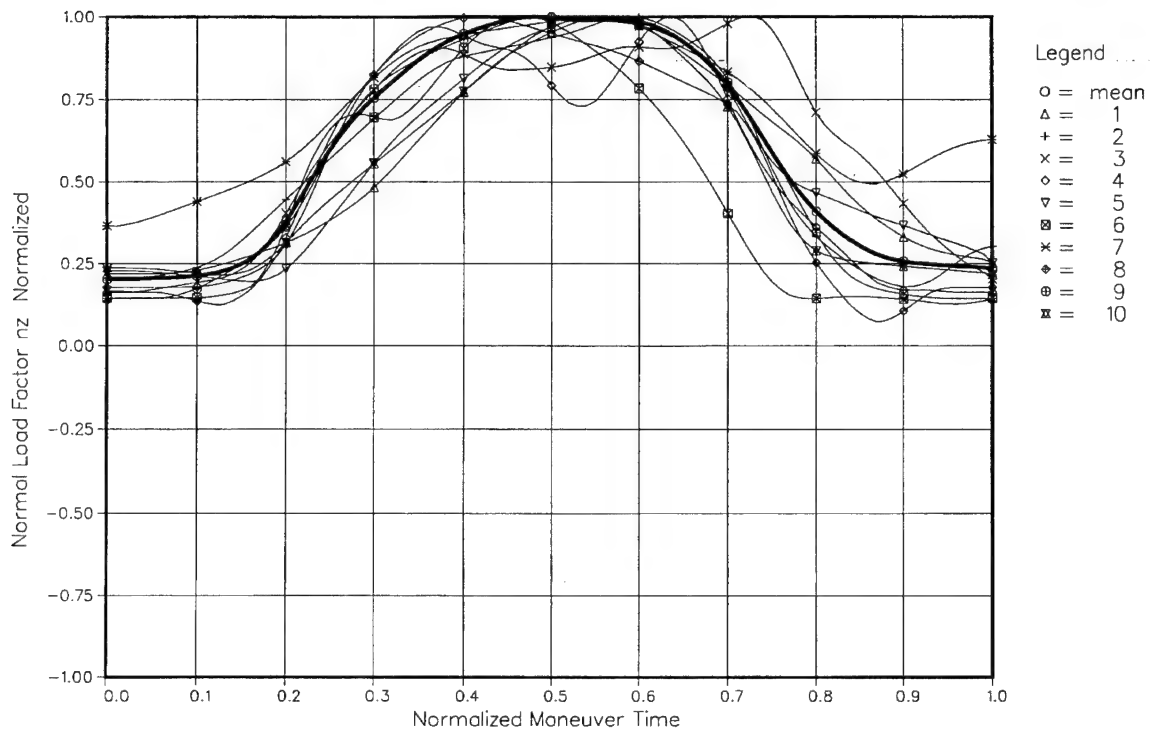Maneuver Comparison

Maneuver Time (sec)	Normal Load Factor n_z (–)	Roll Rate (deg/sec)	Pitch Rate (deg/sec)	Yaw Rate (deg/sec)	Δ Bank Angle (deg)	Maneuver Identification Number
12.16	8.858	75.943	19.477	6.551	90.924	1
9.84	8.189	101.666	21.480	16.247	87.362	2
18.68	7.865	50.883	24.373	16.094	85.339	3
16.26	8.085	184.489	18.424	24.423	91.750	4
15.72	7.197	147.188	18.583	24.886	87.010	5
14.53	8.039	112.038	20.467	17.640	88.477	mean

Recorded extreme values

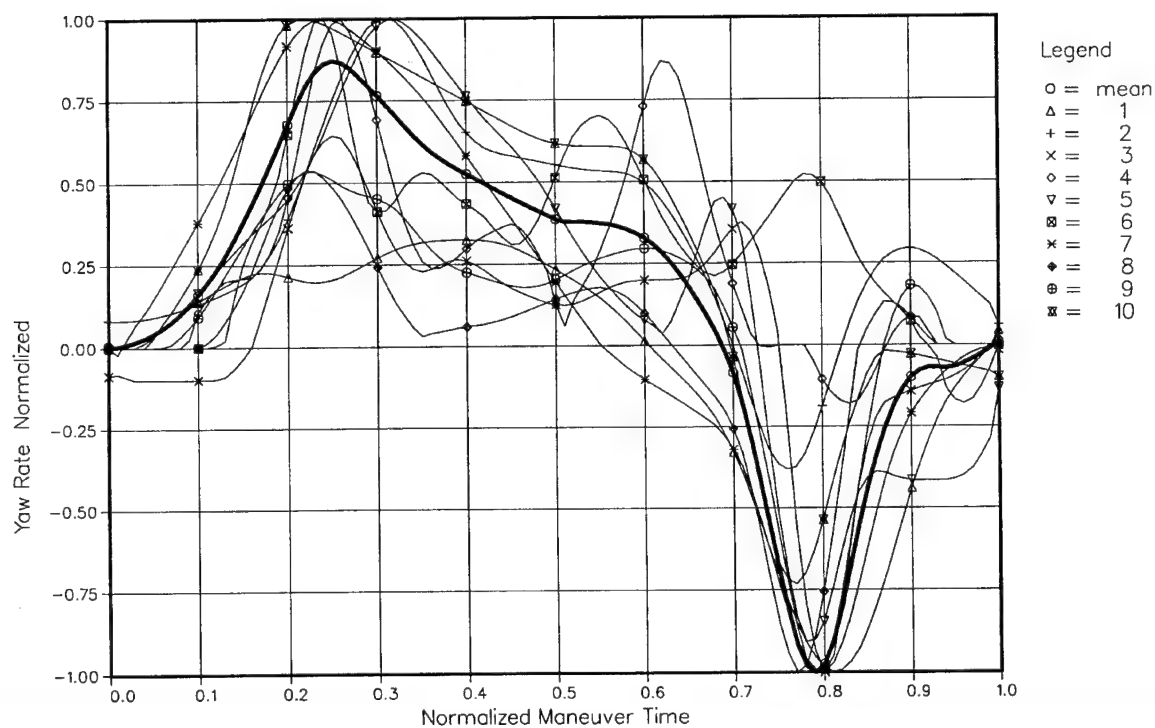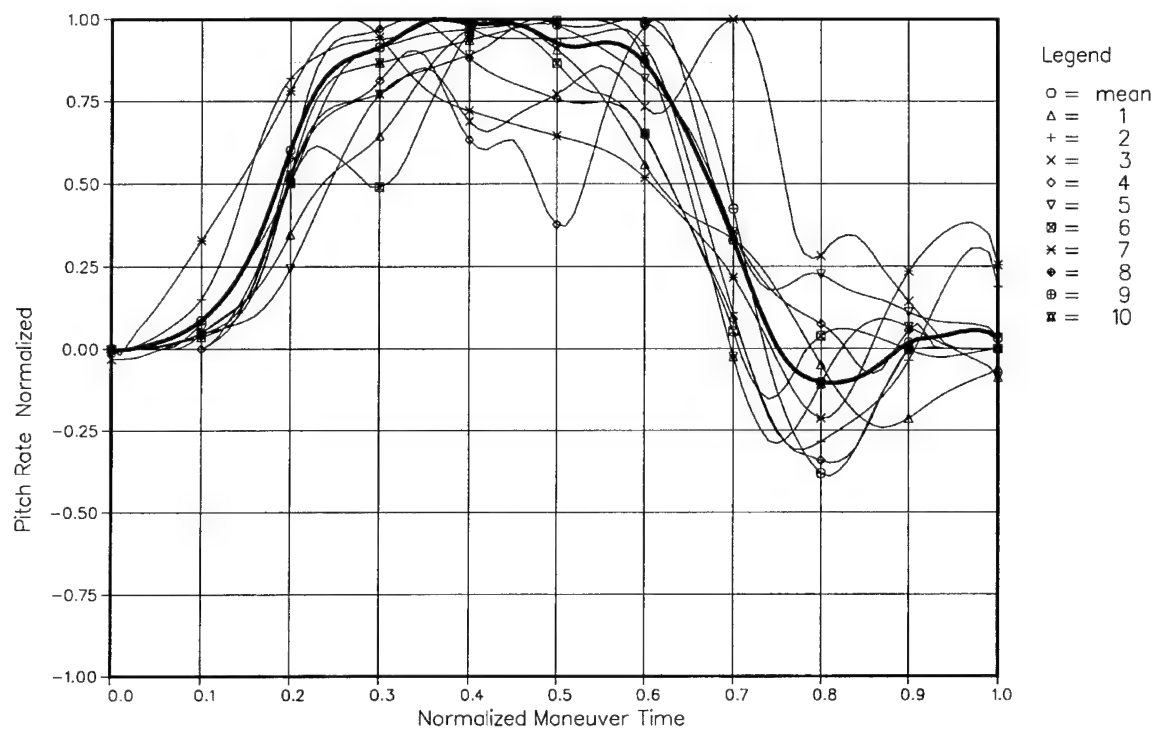### 6.1.4.3 USAF – Normalized Time Histories

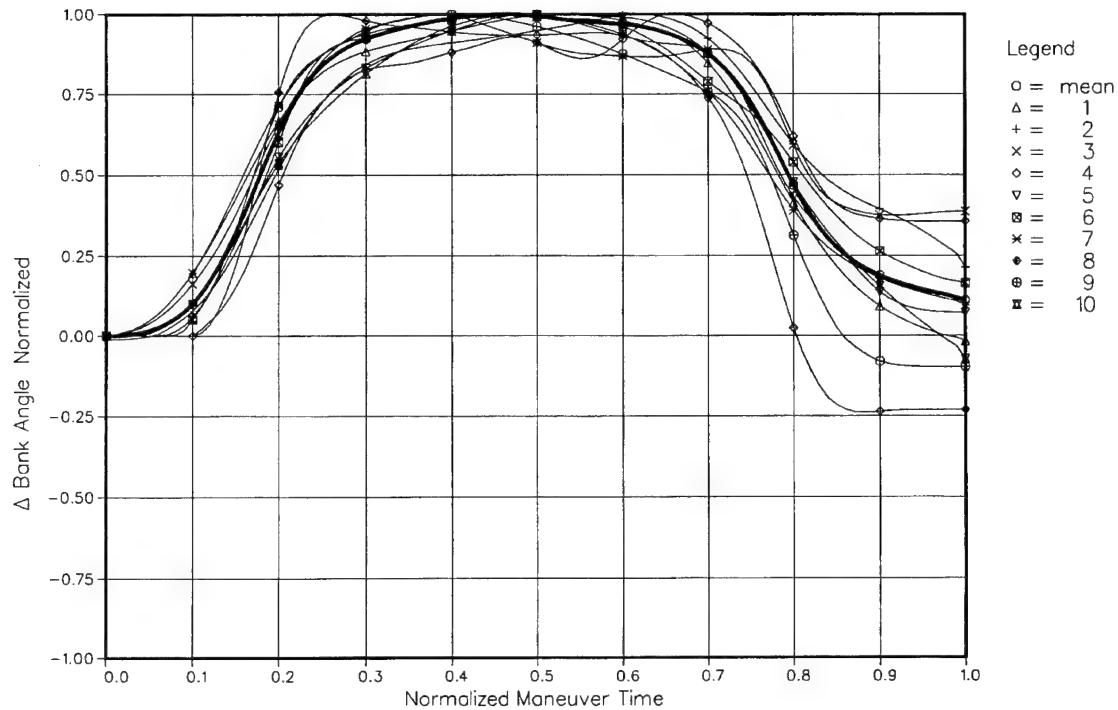### 6.1.4.3.1 USAF – F–16 High g turn
Maneuver Comparison

6.1.4.3 USAF – Normalized Time Histories

6.1.4.3.1 USAF – F–16 High g turn
Maneuver Comparison

6.1.4.3 USAF – Normalized Time Histories

6.1.4.3.1 USAF – F–16 High g turn
Maneuver Comparison

Maneuver Time (sec)	Normal Load Factor n_z (–)	Roll Rate (deg/sec)	Pitch Rate (deg/sec)	Yaw Rate (deg/sec)	Δ Bank Angle (deg)	Maneuver Identification Number
6.20	4.622	112.33	20.597	16.240	93.165	1
8.00	4.074	80.23	12.785	8.021	85.424	2
14.40	5.074	70.03	11.959	8.246	86.727	3
10.80	6.424	63.18	17.189	6.262	93.251	4
11.00	4.422	55.11	10.863	2.865	88.017	5
18.20	6.952	47.88	18.335	6.303	95.376	6
8.80	2.793	76.69	14.007	7.813	78.435	7
10.30	5.680	112.46	16.329	11.373	86.133	8
9.90	7.040	70.03	18.225	13.178	75.608	9
10.40	4.238	54.35	9.167	2.865	95.206	10
10.80	5.132	74.23	14.946	8.317	87.734	mean

Recorded extreme values

6.1.4.3 USAF – Normalized Time Histories

6.1.4.3.2 USAF – F–16 Barrel roll
Maneuver Comparison

6.1.4.3 USAF – Normalized Time Histories

6.1.4.3.2 USAF – F–16 Barrel roll
Maneuver Comparison

6.1.4.3 USAF – Normalized Time Histories

6.1.4.3.2 USAF – F–16 Barrel roll
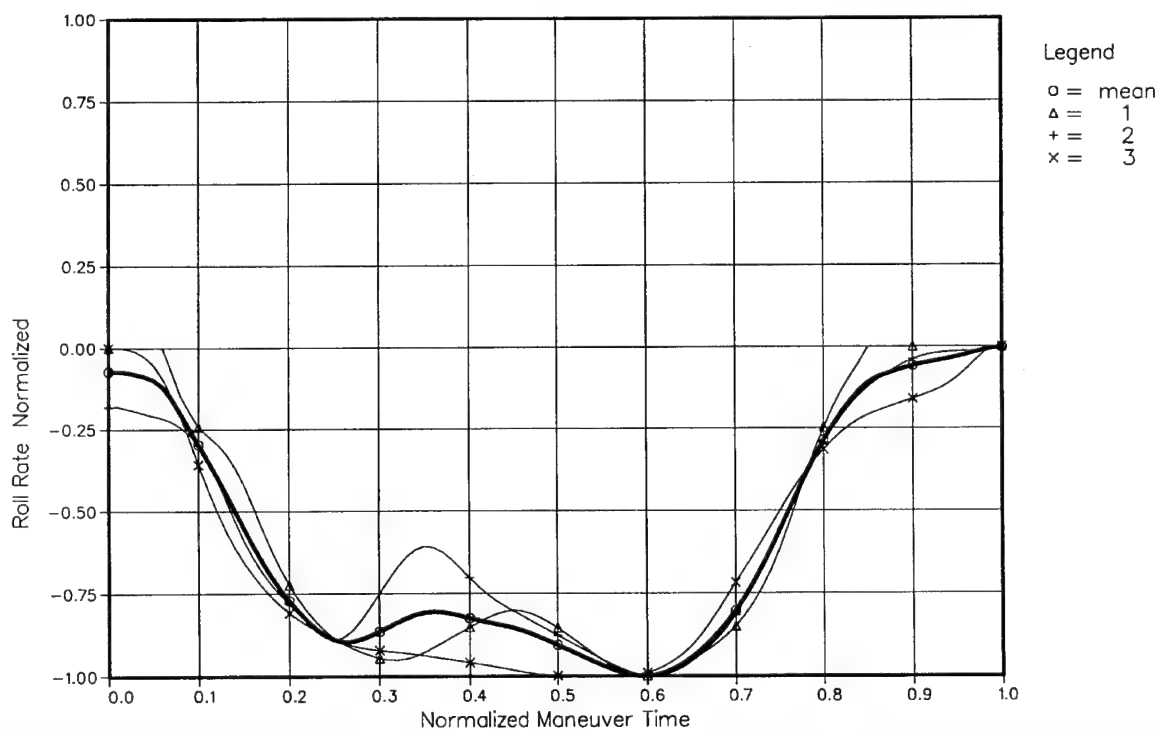
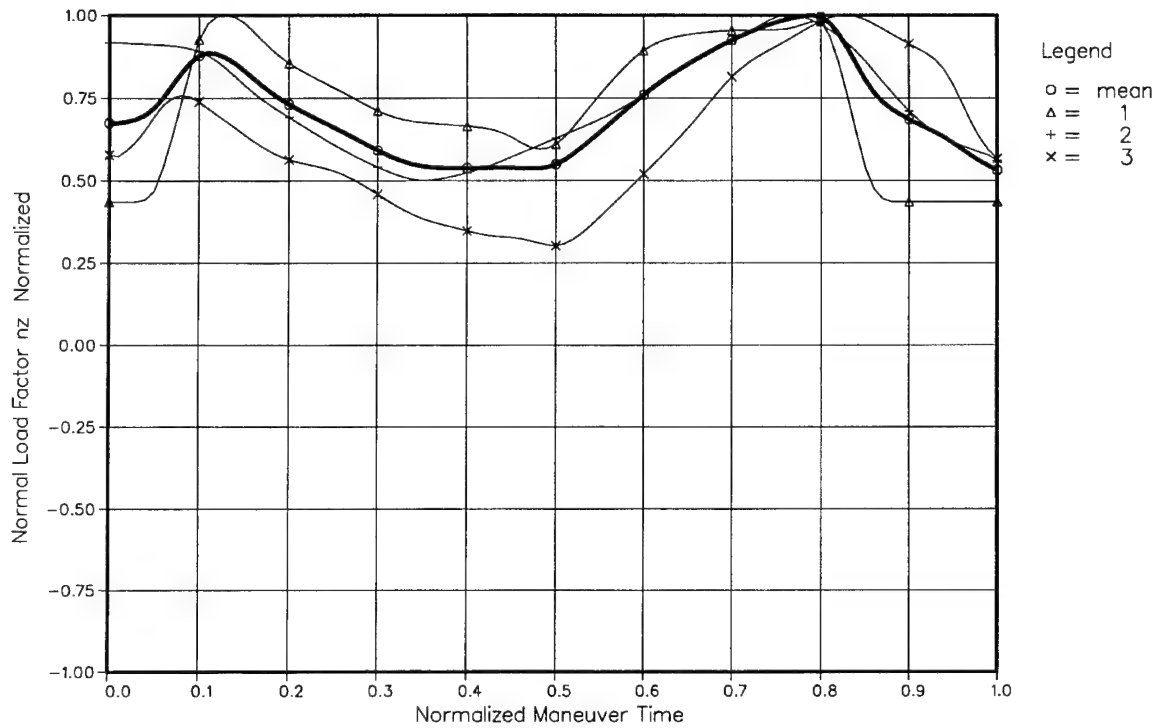   **Maneuver Comparison**

Maneuver Time (sec)	Normal Load Factor n_z (–)	Roll Rate (deg/sec)	Pitch Rate (deg/sec)	Yaw Rate (deg/sec)	Δ Bank Angle (deg)	Maneuver Identification Number
6.00	2.410	96.83	15.470	16.043	471.175	1
7.40	2.619	114.59	12.174	9.061	407.827	2
7.20	1.798	76.78	11.850	10.871	386.781	3
6.86	2.276	96.07	13.165	11.990	421.918	mean

Recorded extreme values

6.1.5.3 CF – Normalized Time Histories

6.1.5.3.1 CF – CF–18 High g turn

Legend

o = mean
△ = m00256
+ = m00442
× = m02006
◇ = m02043
▽ = m02539
⊠ = m02712
✕ = m03199
◆ = m05799
⊕ = m06450
⊠ = m06558
⊞ = m08693
⊠ = m09117
⊠ = m09317
● = m09598

Legend

o = mean
△ = m00256
+ = m00442
× = m02006
◇ = m02043
▽ = m02539
⊠ = m02712
✕ = m03199
◆ = m05799
⊕ = m06450
⊠ = m06558
⊞ = m08693
⊠ = m09117
⊠ = m09317
● = m09598

6.1.5.3 CF – Normalized Time Histories

6.1.5.3.1 CF – CF–18 High g turn

Legend

o = mean
Δ = m00256
+ = m00442
× = m02006
◇ = m02043
▽ = m02539
⊠ = m02712
✕ = m03199
◆ = m05799
⊕ = m06450
⊠ = m06558
⊞ = m08693
⊠ = m09117
⊠ = m09317
● = m09598

Legend

o = mean
Δ = m00256
+ = m00442
× = m02006
◇ = m02043
▽ = m02539
⊠ = m02712
✕ = m03199
◆ = m05799
⊕ = m06450
⊠ = m06558
⊞ = m08693
⊠ = m09117
⊠ = m09317
● = m09598

6.1.5.3 CF – Normalized Time Histories

6.1.5.3.1 CF – CF–18 High g turn

Maneuver Time	Normal Load Factor n_z	Roll Rate	Pitch Rate	Yaw Rate	Δ Bank Angle	Maneuver Identification Number
(sec)	(–)	(deg/sec)	(deg/sec)	(deg/sec)	(deg)	
9.90	4.591	84.93	10.601	6.810	88,600	m00256
6.60	5.216	73.78	13.487	6.493	92.542	m00442
8.60	4.470	37.67	9.921	3.500	78.001	m02006
10.10	6.057	76.68	13.000	6.492	86.224	m02043
11.90	5.331	55.16	12.545	3.498	77.005	m02539
9.00	4.096	61.39	9.030	3.550	81.566	m02712
6.90	5.727	51.99	14.118	7.497	85.818	m03199
10.70	5.227	53.91	10.678	2.501	80.559	m05799
13.50	4.712	71.32	12.762	4.501	79.072	m06450
17.60	5.934	63.09	13.585	4.012	83.770	m06558
11.00	5.067	41.43	11.494	4.510	84.414	m08693
8.90	5.905	89.16	10.866	3.697	88.201	m09117
10.80	5.370	97.92	10.584	3.508	87.612	m09317
11.10	4.858	45.46	9.828	2.473	75.891	m09598
10.57	5.190	64.58	11.607	4.500	83.71	mean

Recorded extreme values

6.1.5.3 CF – Normalized Time Histories

6.1.5.3.2 CF – CF–18 Barrel roll

6.1.5.3 CF – Normalized Time Histories

6.1.5.3.2 CF – CF–18 Barrel roll

Legend

o = mean
△ = m00943
+ = m03135
× = m05523
◇ = m07533
▽ = m08863
⊠ = m10633
× = m10676

Legend

o = mean
△ = m00943
+ = m03135
× = m05523
◇ = m07533
▽ = m08863
⊠ = m10633
× = m10676
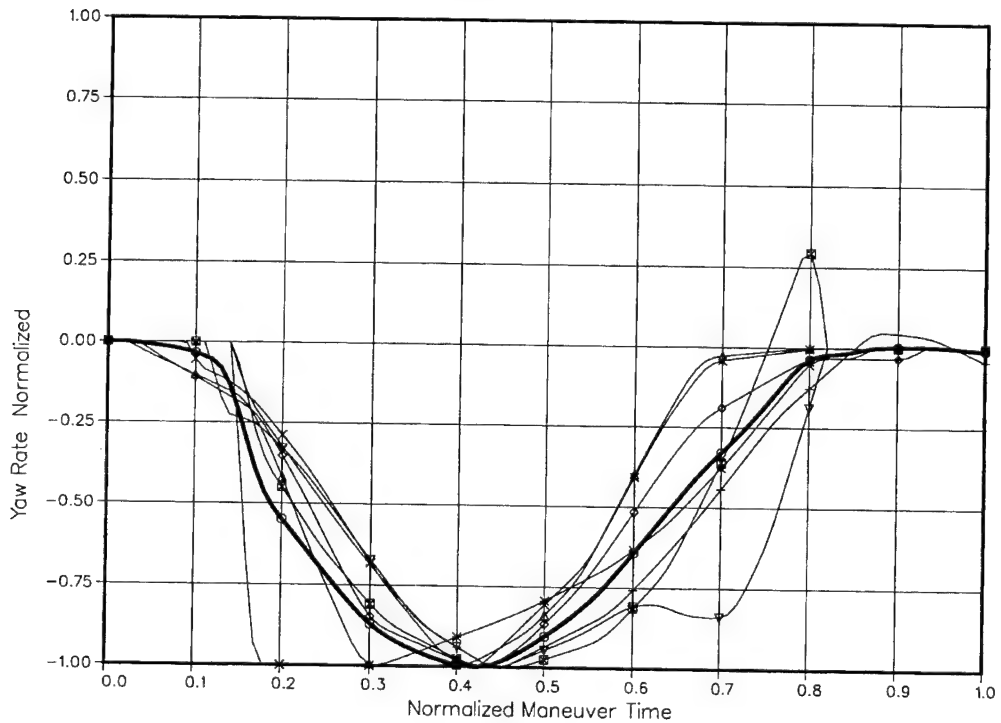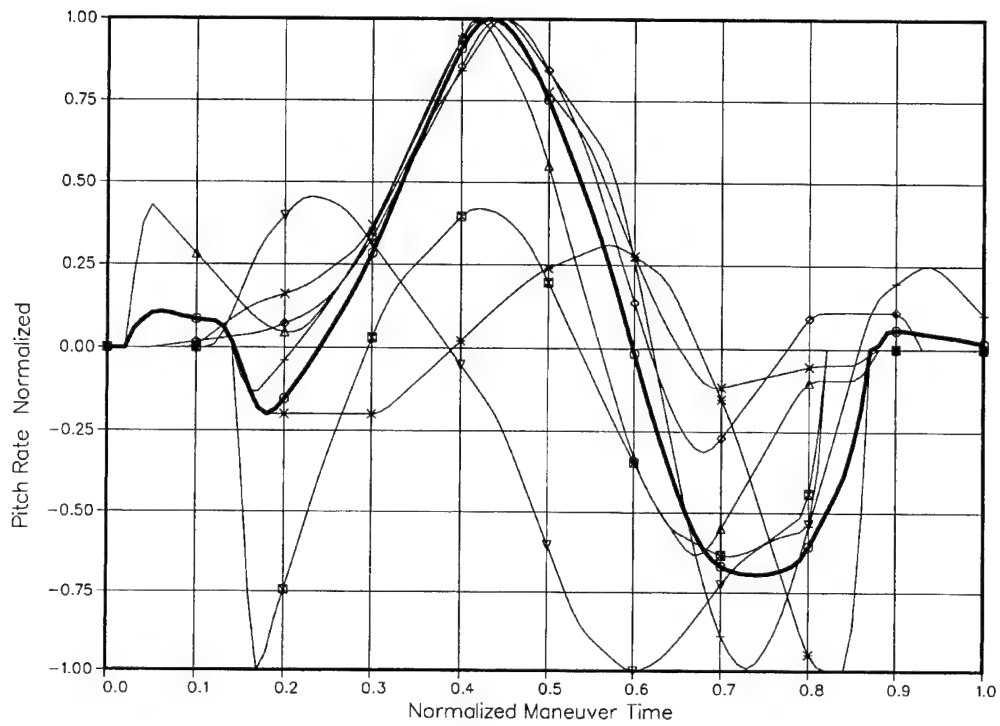
6.1.5.3 CF – Normalized Time Histories

6.1.5.3.2 CF – CF–18 Barrel rol

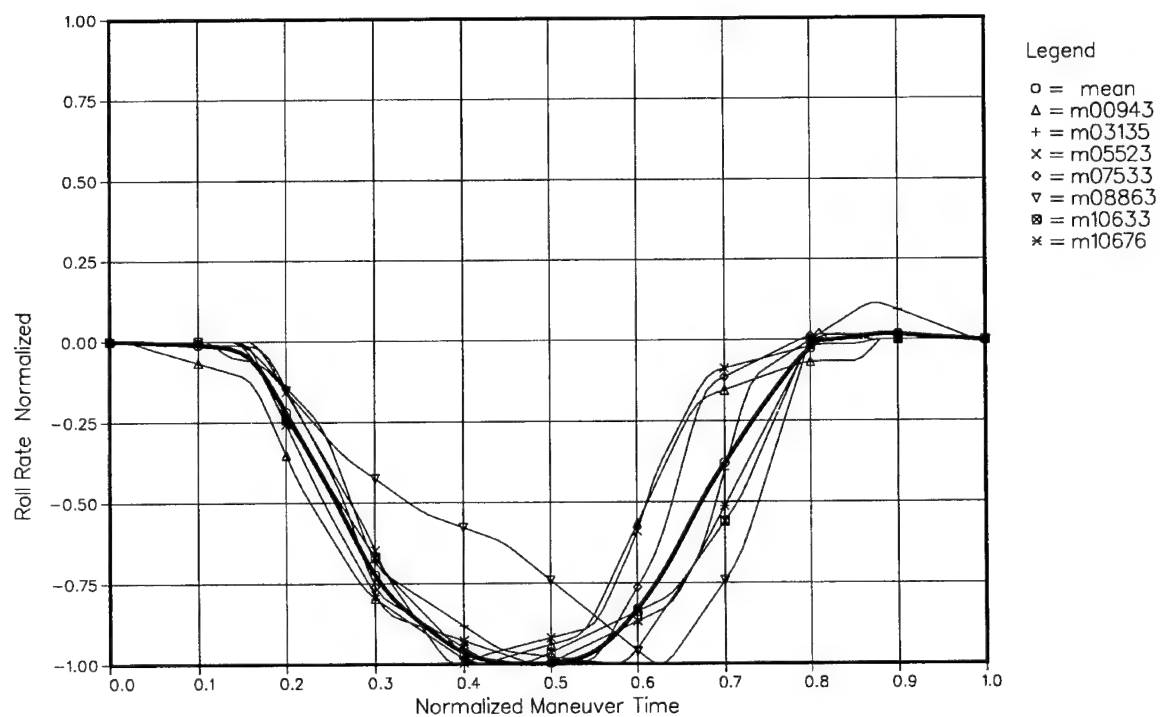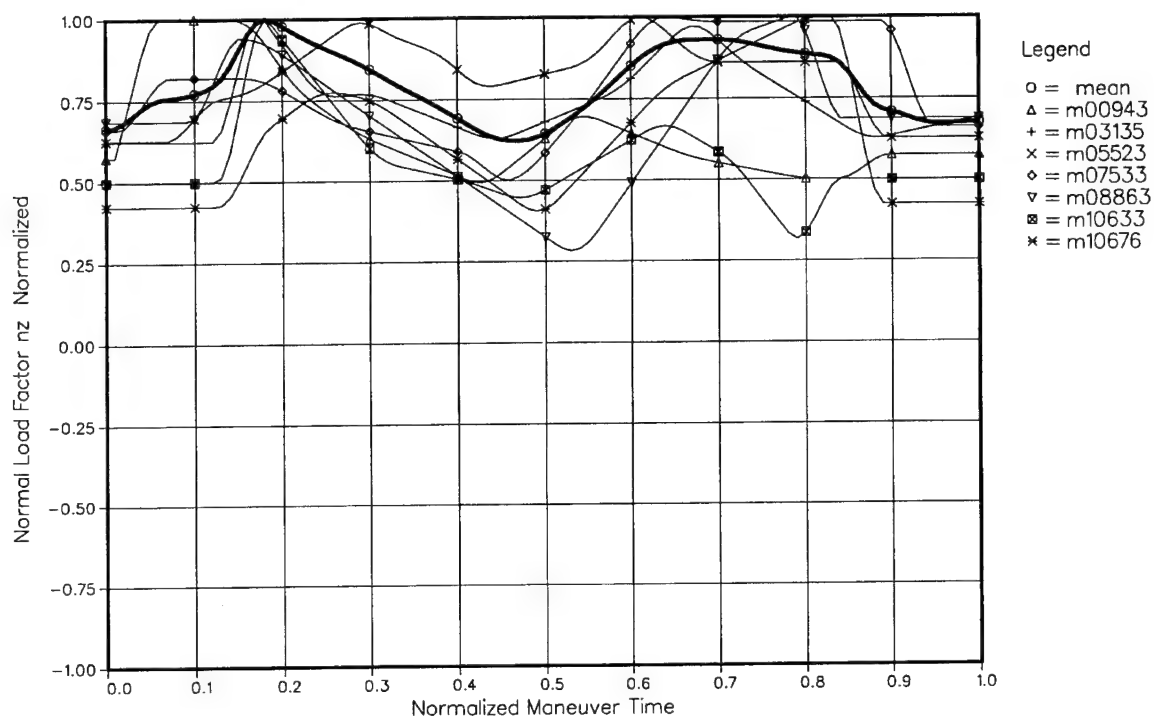

Maneuver Time (sec)	Normal Load Factor n_z (–)	Roll Rate (deg/sec)	Pitch Rate (deg/sec)	Yaw Rate (deg/sec)	Δ Bank Angle (deg)	Maneuver Identification Number
6.550	1.740	119.71	5.458	7.633	369.114	m00943
6.850	1.740	131.97	3.494	9.493	357.331	m03135
5.850	1.620	139.62	4.489	8.495	355.066	m05523
6.850	1.526	123.00	4.581	6.496	366.296	m07533
7.450	0.373	91.79	1.849	5.583	360.212	m08863
3.850	2.240	144.85	5.499	6.512	379.510	m10633
4.150	2.360	144.97	7.500	15.502	393.596	m10676
5.936	1.657	127.99	4.696	8.531	368.732	mean

Recorded extreme values

REPORT DOCUMENTATION PAGE

1. Recipient's Reference	2. Originator's Reference	3. Further Reference	4. Security Classification of Document
	AGARD-AR-340	ISBN 92-836-1030-X	UNCLASSIFIED/ UNLIMITED

5. Originator	Advisory Group for Aerospace Research and Development North Atlantic Treaty Organization 7 rue Ancelle, 92200 Neuilly-sur-Seine, France

6. Title	Structures and Materials Panel Working Group 27 on Evaluation of Loads from Operational Flight Maneuvers

7. Presented at/sponsored by	The Structures and Materials Panel of AGARD

8. Author(s)/Editor(s)	9. Date
Multiple	April 1996

10. Author's/Editor's Address	11. Pages
Multiple	120

12. Distribution Statement	There are no restrictions on the distribution of this document. Information about the availability of this and other AGARD unclassified publications is given on the back cover.

13. Keywords/Descriptors

Flight maneuvers	Data bases
Aircraft (F-16)	Military aircraft
Aircraft (F-18)	Flight loads
Loads (forces)	Computation
Flight characteristics	Methodology

14. Abstract

This AGARD Advisory Report describes an evaluation of a method to derive loads from operational flight maneuvers. The basic assumption of this method is that all operational maneuvers performed in service can be verified as a set of Standard Maneuvers (normalized parameter time histories for each independent maneuver type).

The verification of Standard Maneuvers is based on recordings of relevant maneuver parameters in service and for new tactics/missions on special flights or simulations.

The initial evaluation of the concept done by the Working Group (WG.27) has demonstrated the feasibility of determining loads from operational flight maneuvers. Further work is necessary to expand the scope of the WG.27 investigation and to confirm the WG.27 conclusion.

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